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Fluctuations and Correlations in the HSD Transport Approach

Volodya Konchakovski,

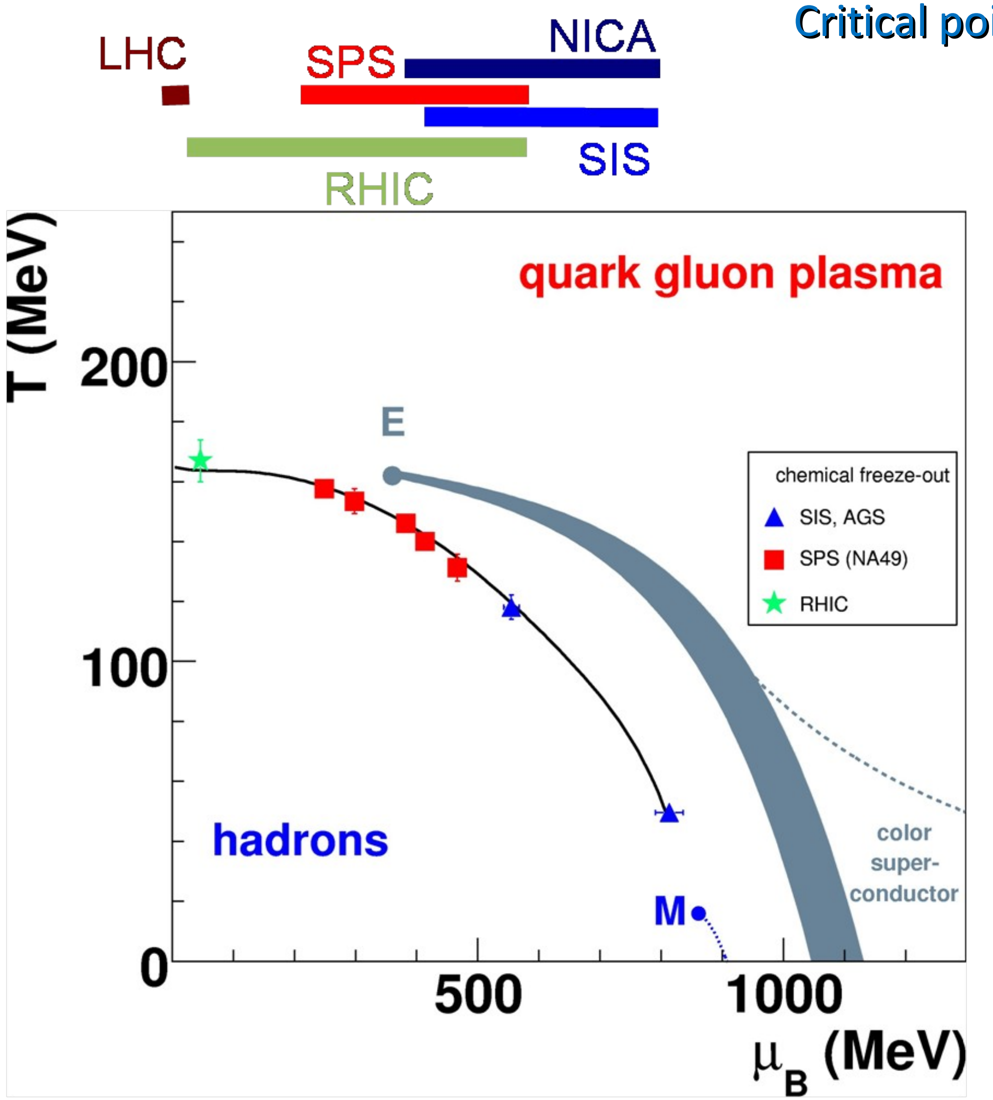
in collaboration with

E. Bratkovskaya, W. Cassing, M. Gorenstein

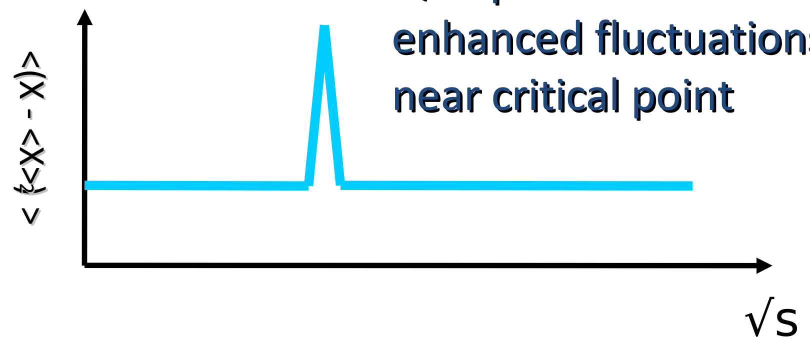
Workshop on Particle Correlations and Femtoscopy
Kiev, Ukraine

September 17, 2010

The Phase Diagram of QCD



Critical point: Fodor and Katz, JHEP 0404, 050 (2004)



QCD predicts enhanced fluctuations near critical point

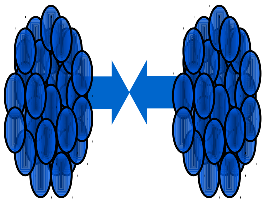
Experimental observations – look for

- baryon number fluctuations
- charge number fluctuations
- multiplicity fluctuations
- particle ratio fluctuations (K/π, p/π)
- mean p_T fluctuations
- 2 particle correlations
- …

"Background" Fluctuations

Many factors lead to the "background" fluctuations that can mask the signal of the critical point and therefore have to be carefully studied and accounted for:

- limited size of colliding system
- fluctuations of initial condition of heavy-ion collisions
- event-by-event fluctuations of the collision geometry
- experimental acceptance
- statistical fluctuations
- …



In order to understand the "background" fluctuations we apply models, where no phase transition is implemented

- wounded nucleon model
- statistical model of hadron-resonance gas
- transport models HSD and UrQMD
- …

Basic Concept of HSD Transport Approaches

HSD – Hadron-String-Dynamics transport approach

Ehehalt, Cassing, Nucl.Phys. A602 (1996) 449;
Cassing, Bratkovskaya, Phys. Rep.308 (1999) 65.

- the phase-space density f_i follows the transport equations

$$\left(\frac{\partial}{\partial t}+\left(\nabla_{\vec{p}} H\right)\nabla_{\vec{r}}-\left(\nabla_{\vec{r}} H\right)\nabla_{\vec{p}}\right) f_i(\vec{r},\vec{p},t)=I_{coll}(f_1,f_2,\ldots,f_M)$$

with collision terms I_{coll} describing:

- elastic and inelastic hadronic reactions:

  baryon-baryon, meson-baryon, meson-meson

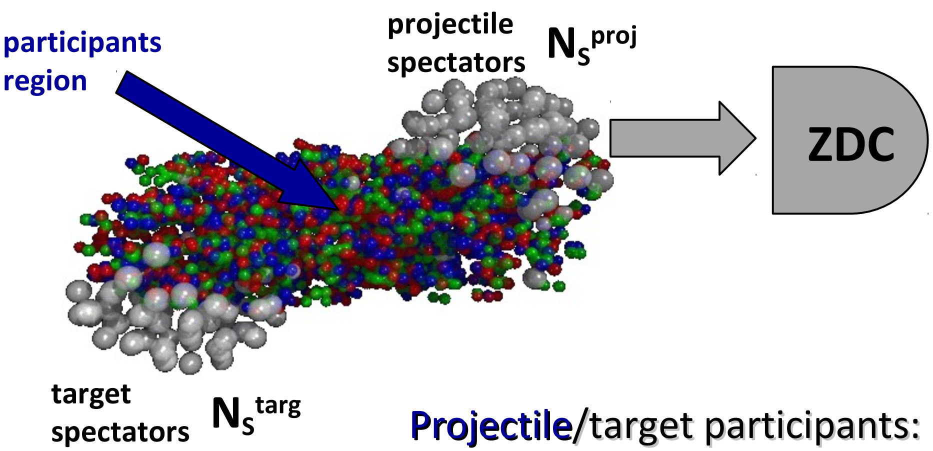
- formation and decay of baryonic and mesonic resonances
- string formation and decay

  (for inclusive particle production: BB -> X , mB -> X, X =many particles)

- implementation of detailed balance on the level of 1<->2 and 2<->2 reactions (+ 2<->n multi-particle reactions in HSD !)
- no explicit phase transition from hadronic to partonic degrees of freedom (implemented in PHSD: Cassing, Bratkovskaya Phys. Rev. C78 (2008) 034919)

Fluctuations in the number of participants

VK, Haussler, Gorenstein, Bratkovskaya, Bleicher, Stoecker, Phys. Rev. C73 (2006) 034902; C78 (2008) 024906

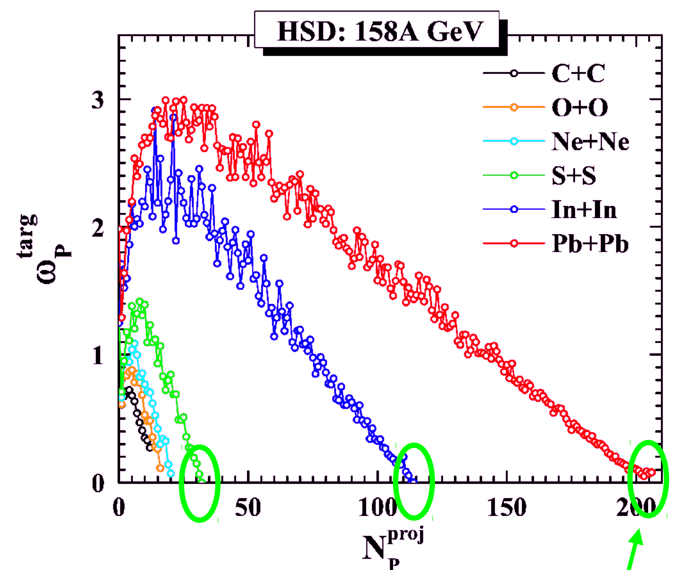


Projectile/target participants:

$N_p^{proj} = A - N_s^{proj}$

$N_p^{targ} = A - N_s^{targ}$

Participants number fluctuations **reflect in the observable fluctuations** (e. g. multiplicity fluctuations)

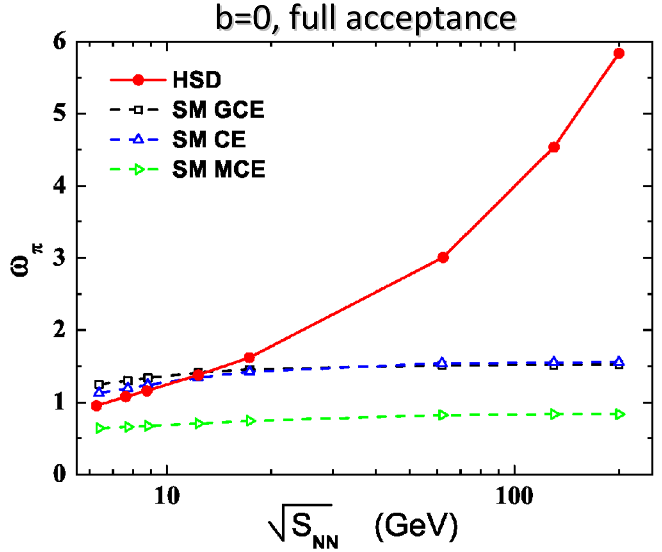


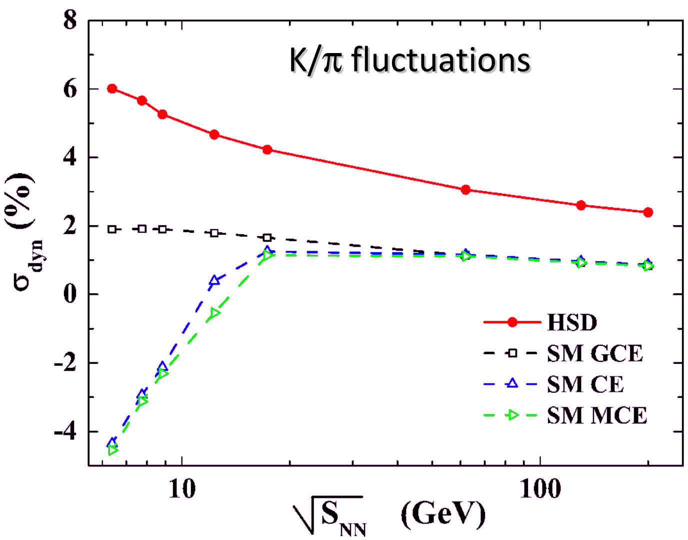
Even with fixed number of **projectile participants N_p^{proj}** the full number of participants N_p can fluctuate due to participant fluctuation in the **target N_p^{targ}**.

To get rid of the fluctuations in the participant number one needs to consider only **the most central collisions**!

Statistical and HSD Model Results for Ratio Fluctuations

Gorenstein, Hauer, VK, Bratkovskaya, Phys. Rev. C 79(2009) 024907





Large difference in SM and the transport model predictions for ω with increasing energy!

For ratio fluctuations the measure

$$\sigma^2 \equiv \frac{\langle \Delta (N_A/N_B)^2 \rangle}{\langle N_A/N_B \rangle^2}$$

is used. Assuming $|\Delta N_A| \ll \langle N_A \rangle, \quad |\Delta N_B| \ll \langle N_B \rangle$
it can be rewritten as:

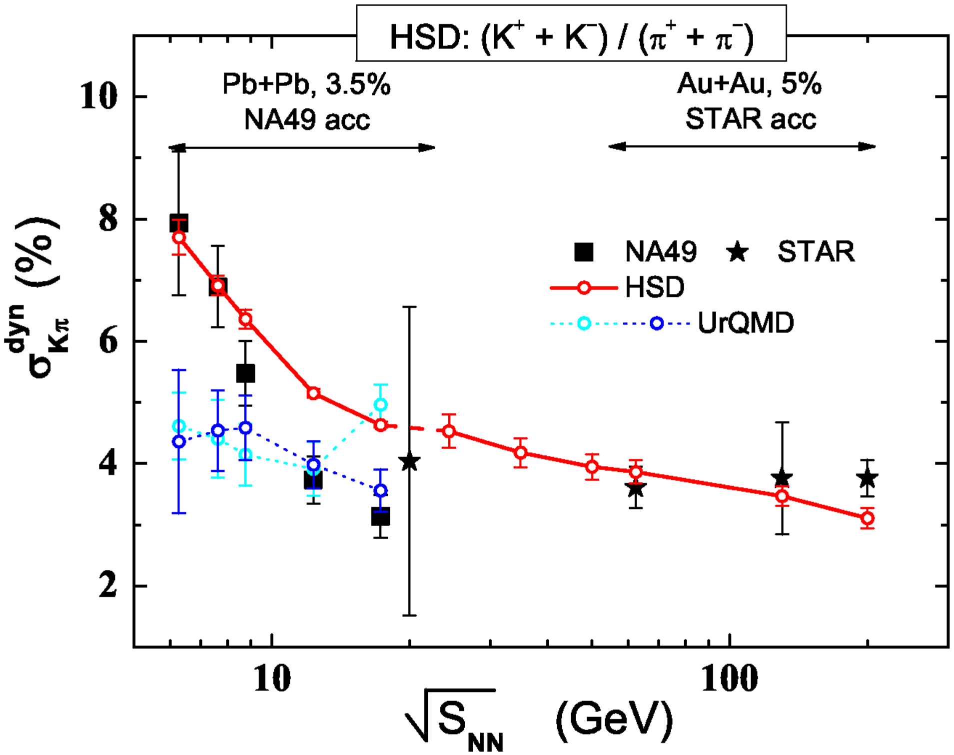
$$\sigma^2 \cong \frac{\omega_A}{\langle N_A \rangle} + \frac{\omega_B}{\langle N_B \rangle} - 2\rho_{AB}\left[\frac{\omega_A \omega_B}{\langle N_A \rangle \langle N_B \rangle}\right]^{1/2}$$

After subtraction of σ for mixed events one gets:

$$\sigma_{dyn} \equiv \pm |\sigma^2 - \sigma^2_{mix}|^{1/2} \times 100\%$$

- For σ_{dyn} SM and HSD differ at low energies in contrast to ω!

K/π Ratio Fluctuations: Transport vs Data



- Exp. data show a plateau from top SPS up to RHIC energies and an increase towards lower SPS energies.

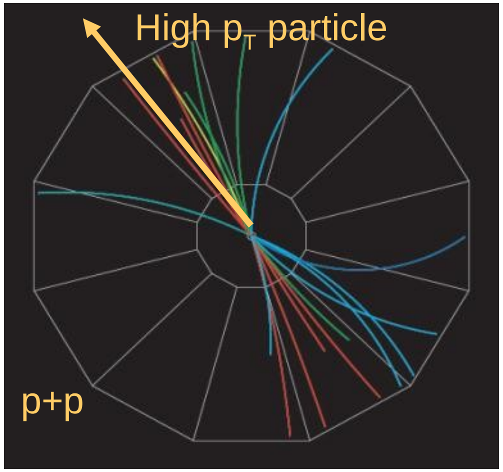
evidence for a critical point at low SPS energies ?

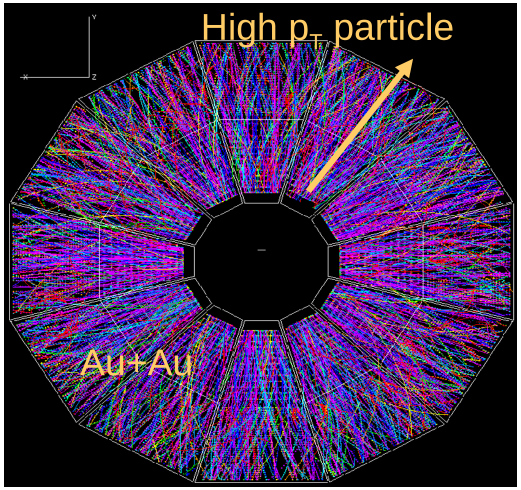
- But the HSD results shows the same behavior.

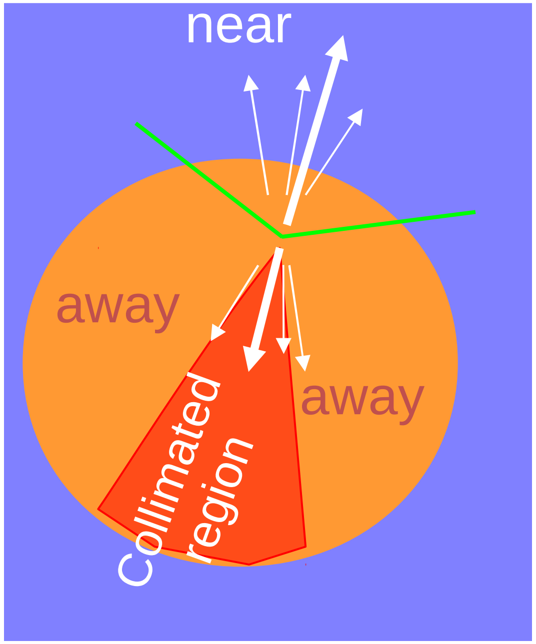
- K/π ratio fluctuations are driven by hadronic sources. No evidence for a critical point in the K/π ratio ?

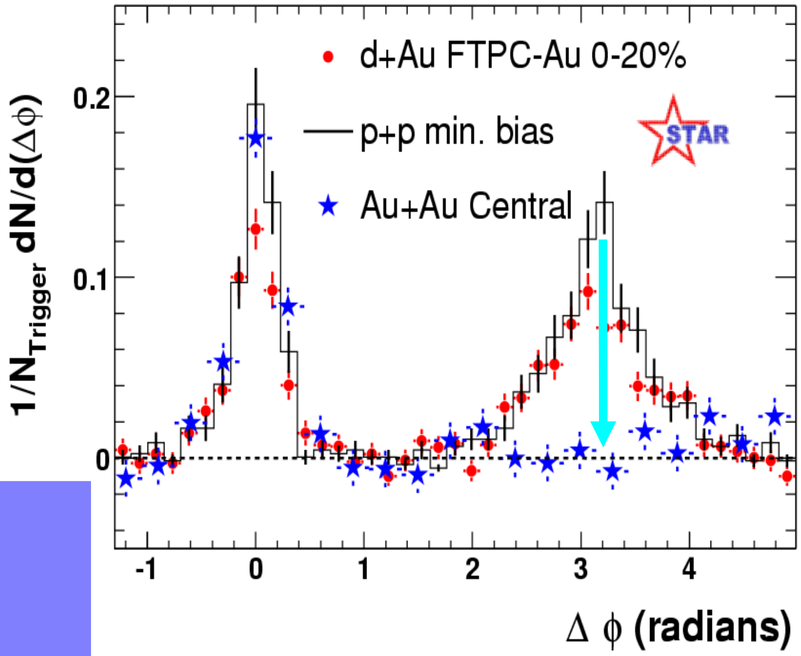
HSD: Phys. Rev. C 79 (2009) 024907
UrQMD: J. Phys. G 30 (2004) S1381, PoS CFRNC2006,017
NA49: 0808.1237
STAR: 0901.1795

Jet energy loss



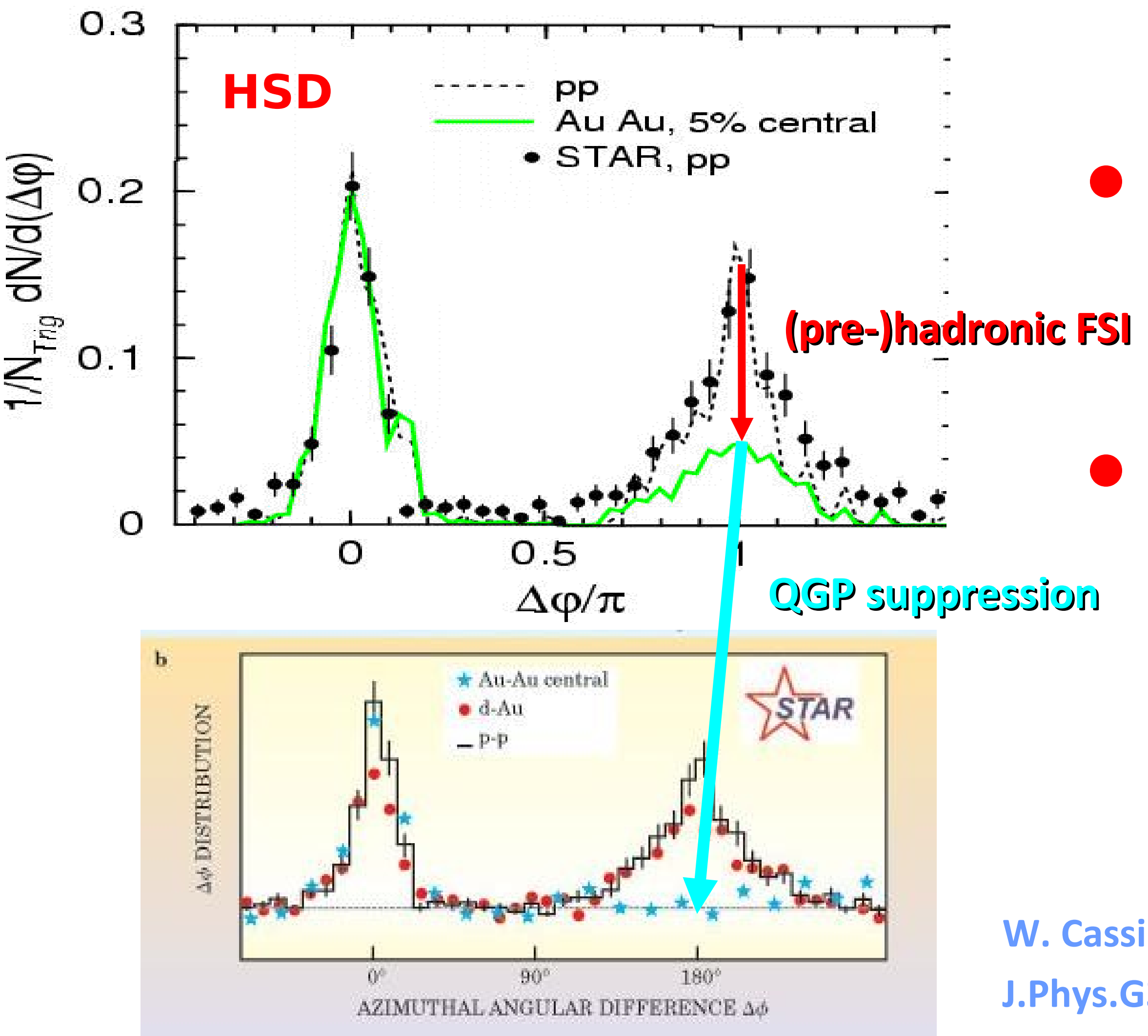






QGP suppression ?!

Jet suppression: dN/dφ (HSD)

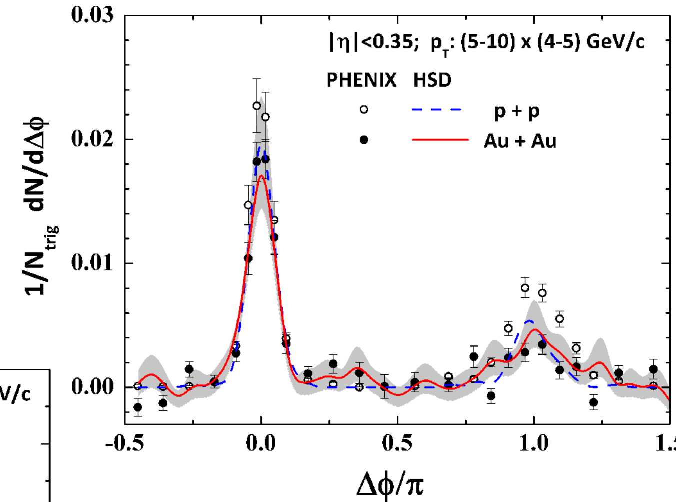


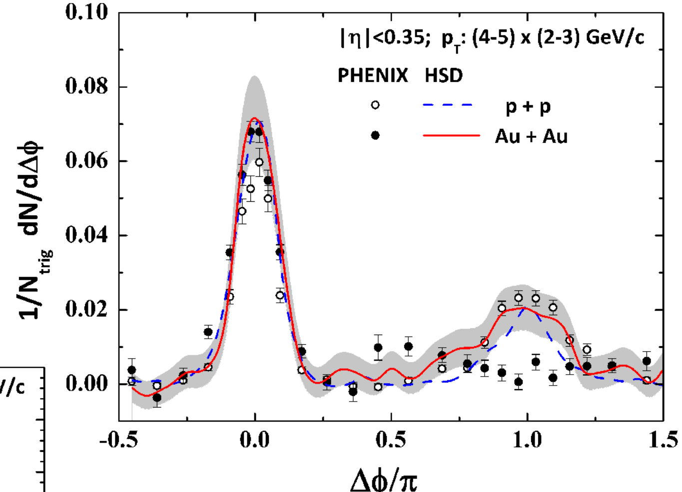
- The jet angular correlations for pp are fine!
- The near-side jet angular correlation for central Au+Au is well described, but the suppression of the far-side jet is too low!

W. Cassing, K. Gallmeister and C. Greiner, J.Phys.G30 (2004) S801; NPA 748 (2005) 241

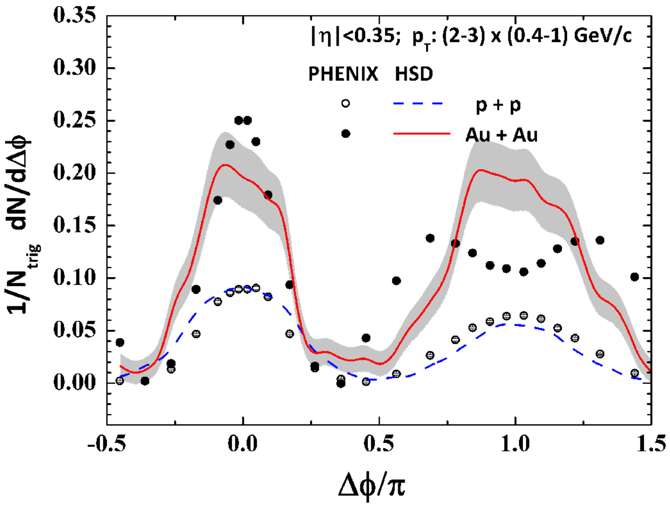
New: nonperturbative treatment of all medium interactions

Suppression of away-side jet seen in central A+A collisions cannot be explained only by (pre-)hadronic interactions in the medium as obtained in HSD for different criteria for the trigger particle.



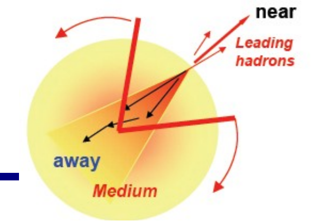


More energetic trigger particle



VK, Bratkovskaya, Cassing, Gorenstein, Phys.Rev.C in press, [1007.0557]

New experimental data: $\phi-\eta$ correlations



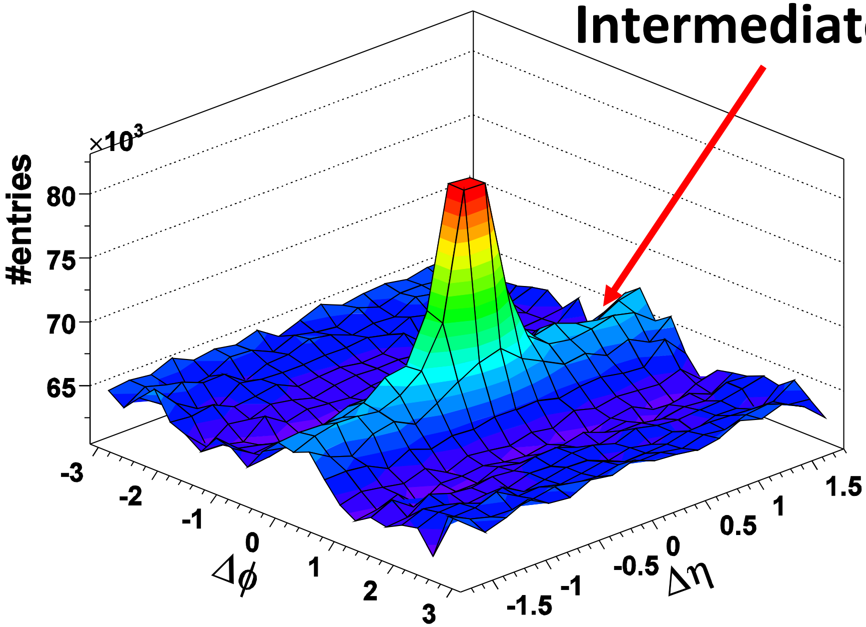
STAR

Eur.Phys.J.C61 (2009) 569-574

PHOBOS

Phys.Rev.Lett.104 (2010) 062301

Intermediate p_T: near-side ridge



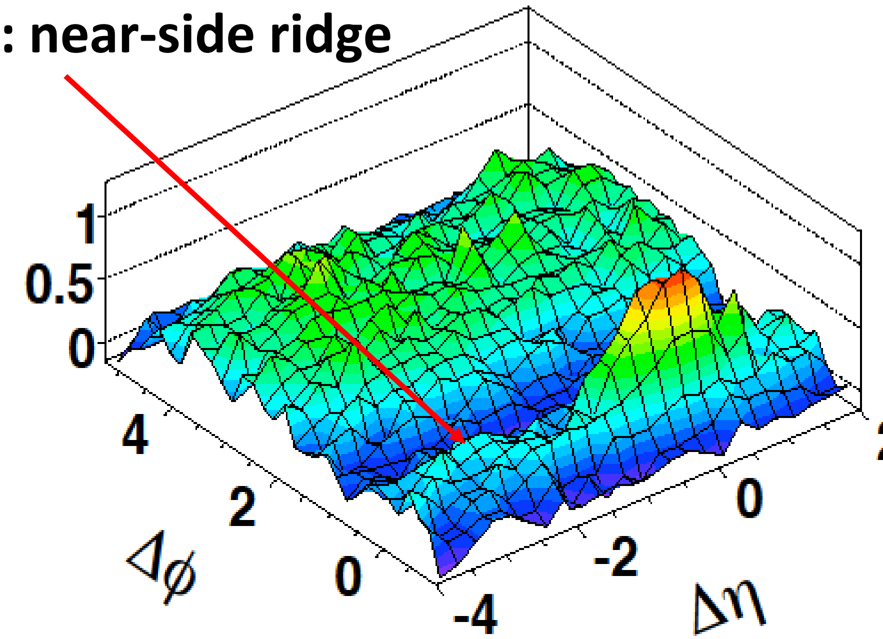
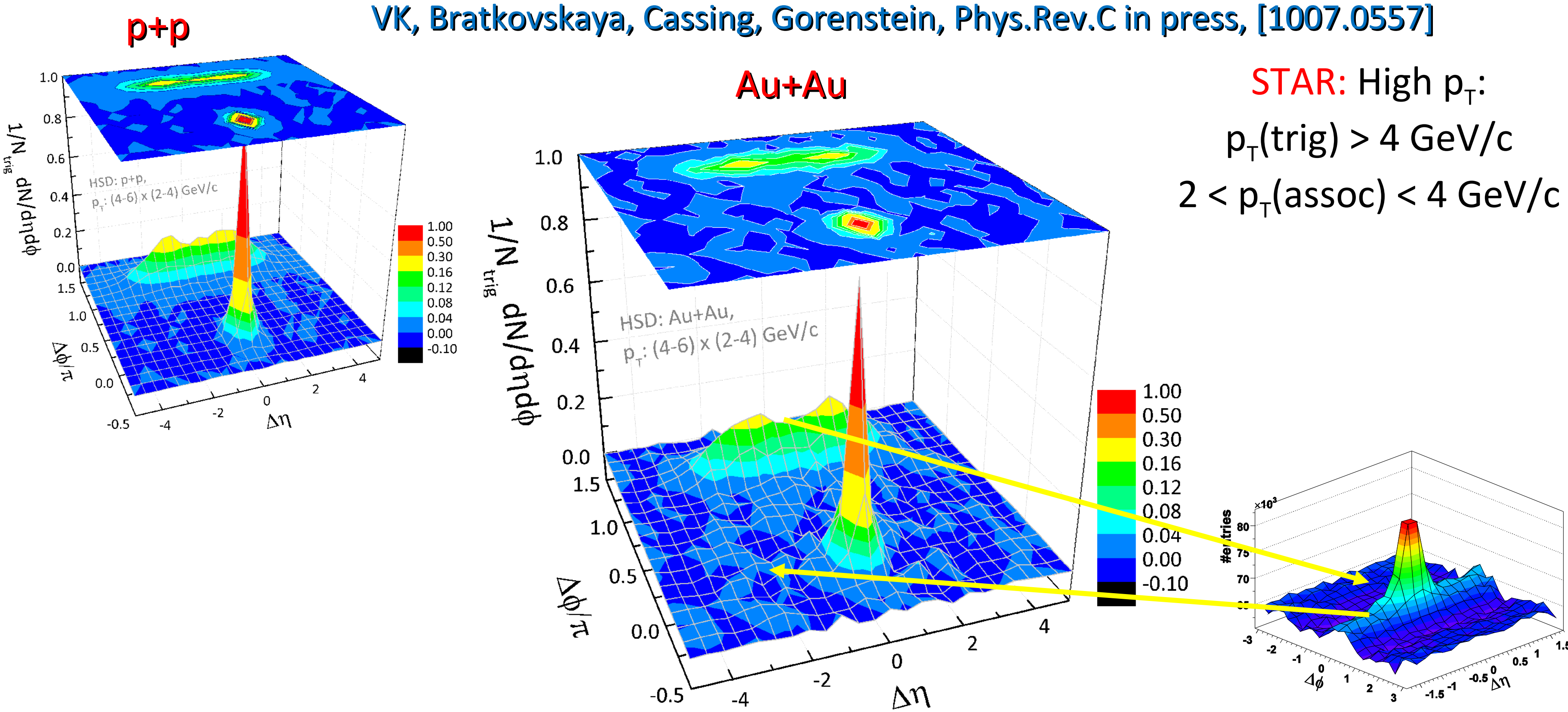


Fig. 1. (Color on-line) Preliminary associated particle distributions in $\Delta\eta$ and $\Delta\phi$ with respect to the trigger hadron for associated particles with 2 GeV$/c < p_T^{assoc} < p_T^{trig}$ in 0-12% central Au+Au collisions. Two different trigger p_T selections are shown: $3 < p_T^{trig} < 4$ GeV$/c$ (upper panel) and $4 < p_T^{trig} < 6$ GeV$/c$ (lower panel). No background was subtracted.

FIG. 2: (color online) Per-trigger correlated yield with $p_T^{trig} > 2.5$ GeV$/c$ as a function of $\Delta\eta$ and $\Delta\phi$ for $\sqrt{s}$ and $\sqrt{s_{NN}}$=200 GeV (a) PYTHIA p+p and (b) PHOBOS 0-30% central Au+Au collisions. (c) Near-side yield integrated

I: High p_T particle correlations in HSD vs. STAR data

VK, Bratkovskaya, Cassing, Gorenstein, Phys.Rev.C in press, [1007.0557]



STAR: High p_T:
p_T(trig) > 4 GeV/c
2 < p_T(assoc) < 4 GeV/c

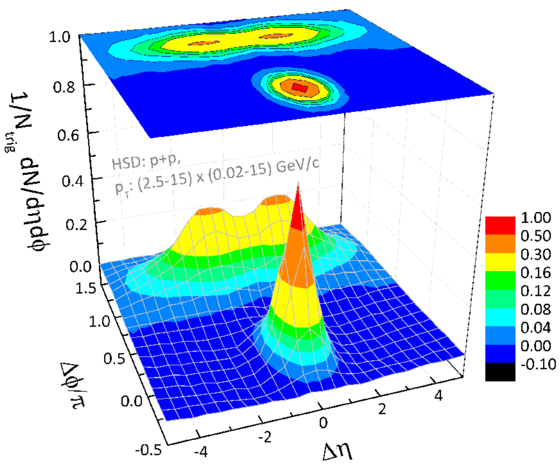
HSD vs. STAR:

- away side structure is suppressed in Au+Au collisions in comparison to p+p, however, HSD doesn't provide enough high p_T suppression to reproduce the STAR Au+Au data
- near-side ridge structure is NOT seen in HSD!

II: Intermediate p_T particle correlations in HSD vs. PHOBOS data

VK, Bratkovskaya, Cassing, Gorenstein, Phys.Rev.C in press, [1007.0557]

p+p

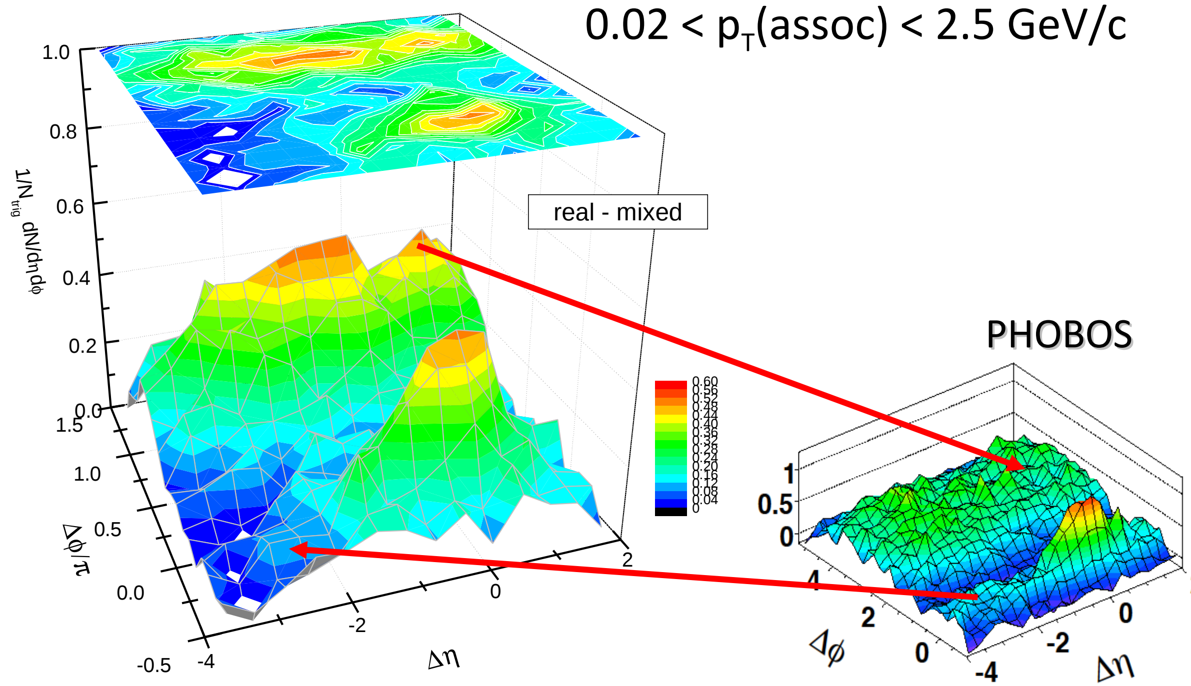


PHOBOS: Intermediate p_T:

p_T(trig) > 2.5 GeV/c;

0.02 < p_T(assoc) < 2.5 GeV/c

Au+Au



HSD vs. PHOBOS:

- away side structure is suppressed in Au+Au collisions in comparison to p+p, however, HSD doesn‘t provide enough high p_T suppression to reproduce the PHOBOS Au+Au data
- near-side ridge structure is NOT seen in HSD!

Summary

- The systematic study of fluctuations and correlations in microscopic **transport approaches** has been performed as a function of centrality, energy, experimental acceptance and system size. The results can be used as **a baseline** for the experimental and theoretical study **of deconfinement and the critical point**.

- The **fluctuations in the number of target participants** – for fixed projectile participants - strongly influence all observable fluctuations.

- HSD results for the **K/π ratio fluctuations** show that it grows at low SPS energies, the same as in the data!

- The **near-side ridge** in the wide range of pseudorapidity Δη as well as strong **far-side jet suppression** seen in the experimental data from the STAR, PHENIX and PHOBOS collaborations **are not reproduced by hadron-string dynamics**

Thanks to:

Elena Bratkovskaya

Mark Gorenstein

Wolfgang Cassing

Olena Linnyk

Vitalii Ozvenchuk

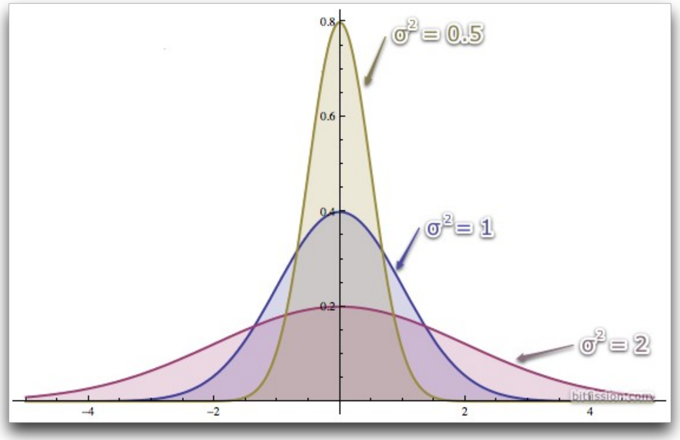
Viktor Begun

Beyond the Average Quantities: Fluctuations and Correlations

While average values of distributions can coincide, the higher moments of distributions can be different

$$\langle X^n \rangle \equiv \sum_X X^n P(X)$$

(where X – is an observable e.g. multiplicity)



One can construct measures to study fluctuations and correlations:

- Multiplicity fluctuations in some acceptance (charge, strangeness, etc.)

$$\omega = \frac{\langle (\Delta N)^2 \rangle}{\langle N \rangle} = \frac{\langle N^2 \rangle - \langle N \rangle^2}{\langle N \rangle}$$

- Ratio fluctuations in the acceptance (ratio of different species)

$$\sigma_{dyn}, \;\; \nu, \;\; etc.$$

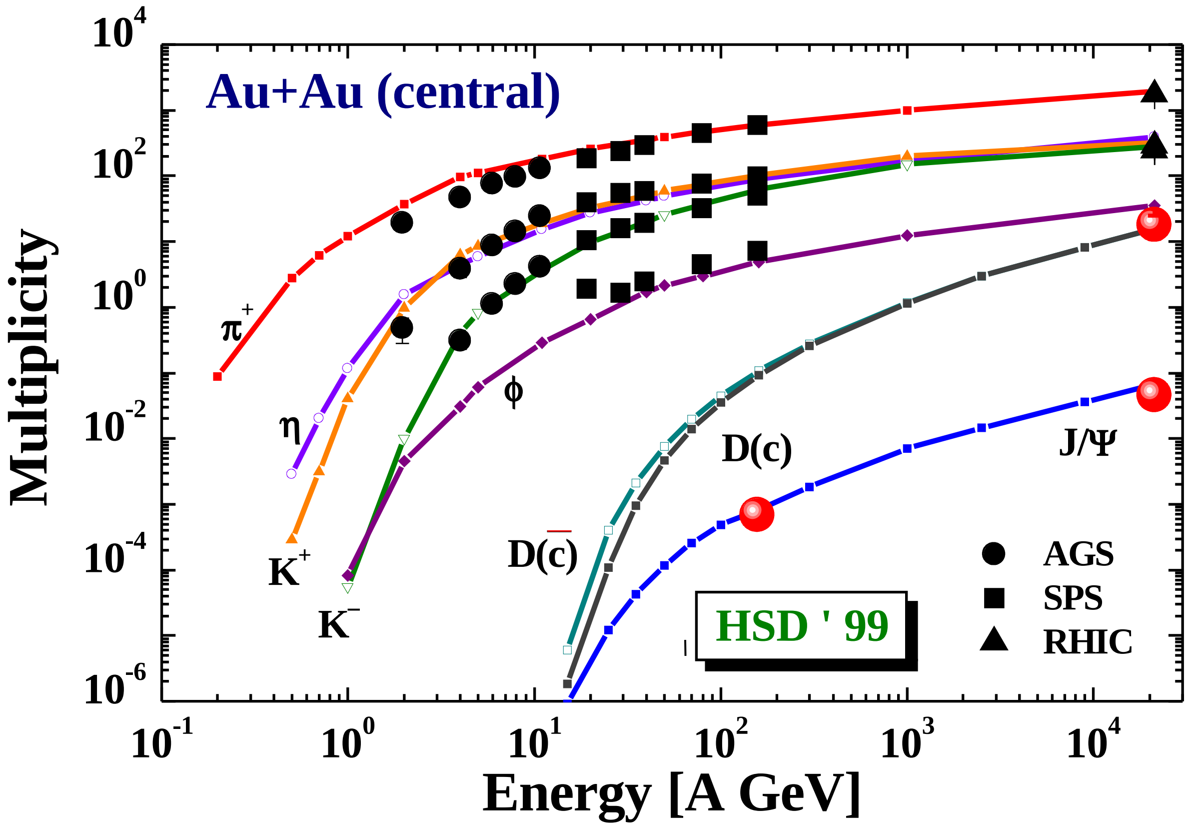
- Correlations between different species in the acceptance

$$\rho_{AB} \equiv \frac{\langle \Delta N_A \Delta N_B \rangle}{\left[\langle (\Delta N_A)^2 \rangle \langle (\Delta N_B)^2 \rangle \right]^{1/2}}$$

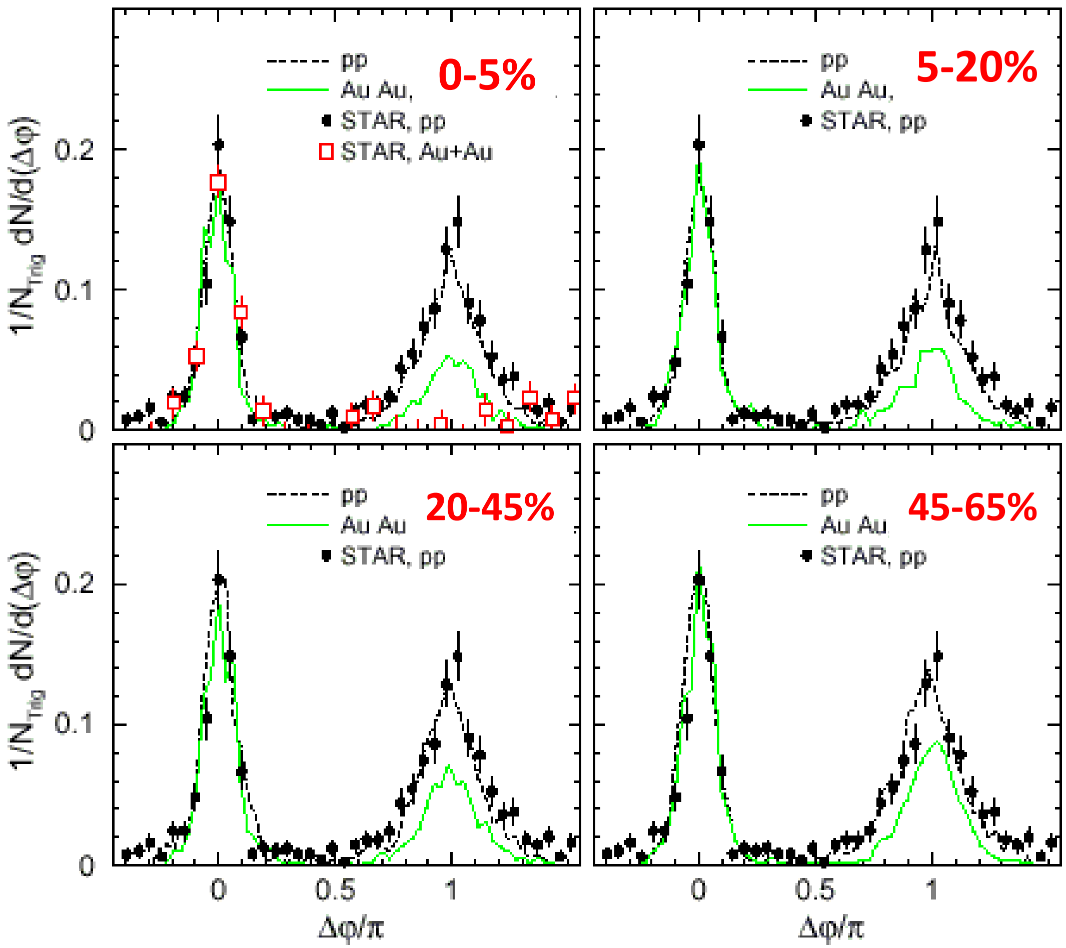
- Correlations between multiplicities in different acceptance intervals
- Skewness and kurtosis

HSD – a microscopic model for heavy-ion reactions

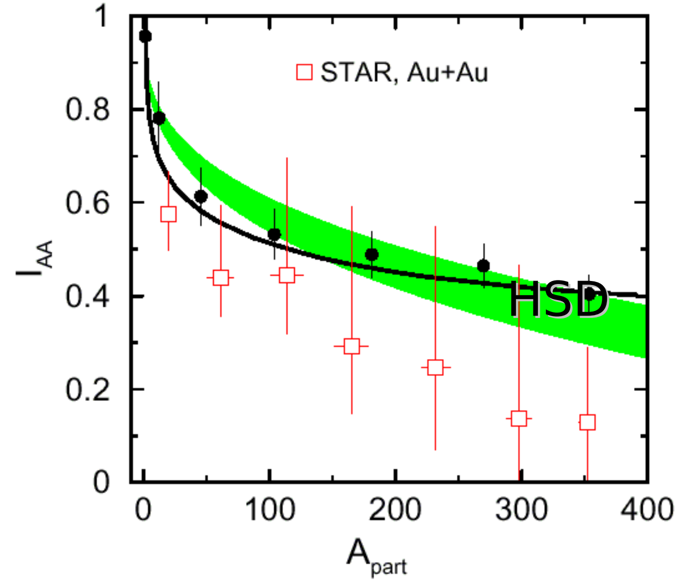
- very good description of particle production in pp, pA, AA reactions
- unique description of nuclear dynamics from low (~100 MeV) to ultrarelativistic (~20 TeV) energies



Centrality dependence of angular correlations



Near-side jet is unchanged for all centralities



$$I_{AA} = \frac{\int C_{AA}(\phi) d\phi}{\int C_{pp}(\phi) d\phi}$$

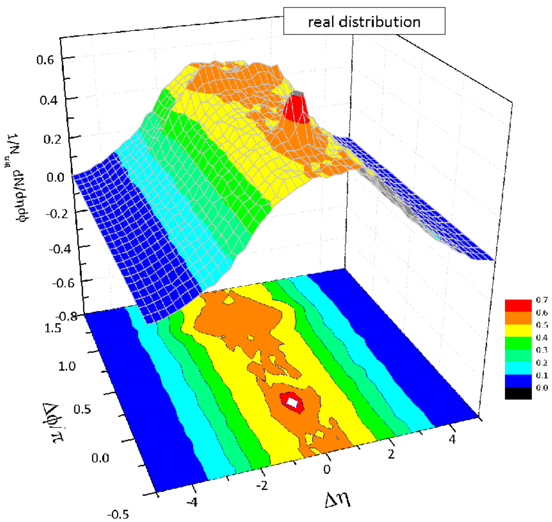
Missing suppression of far-side jet in central reactions!

W. Cassing, K. Gallmeister

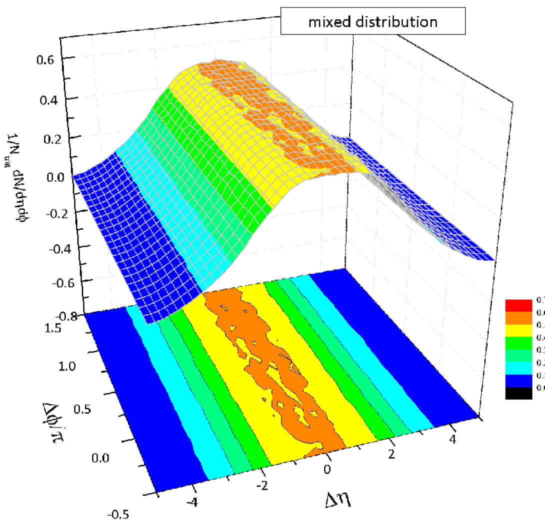
NPA 748 (2005) 241

Background subtraction for Au+Au collisions

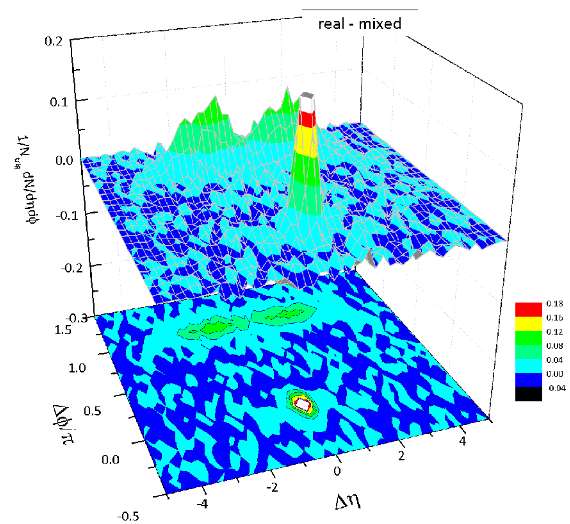
Real distribution



Mixed distribution



Real-Mixed distribution



- **Background can mask the signal and should be subtracted. Especially for soft p_T cuts when there are a lot of bulk particles in the associative p_T region.**