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BITP

Fluctuations and Correlations as a signal of Deconfinement

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in collaboration with

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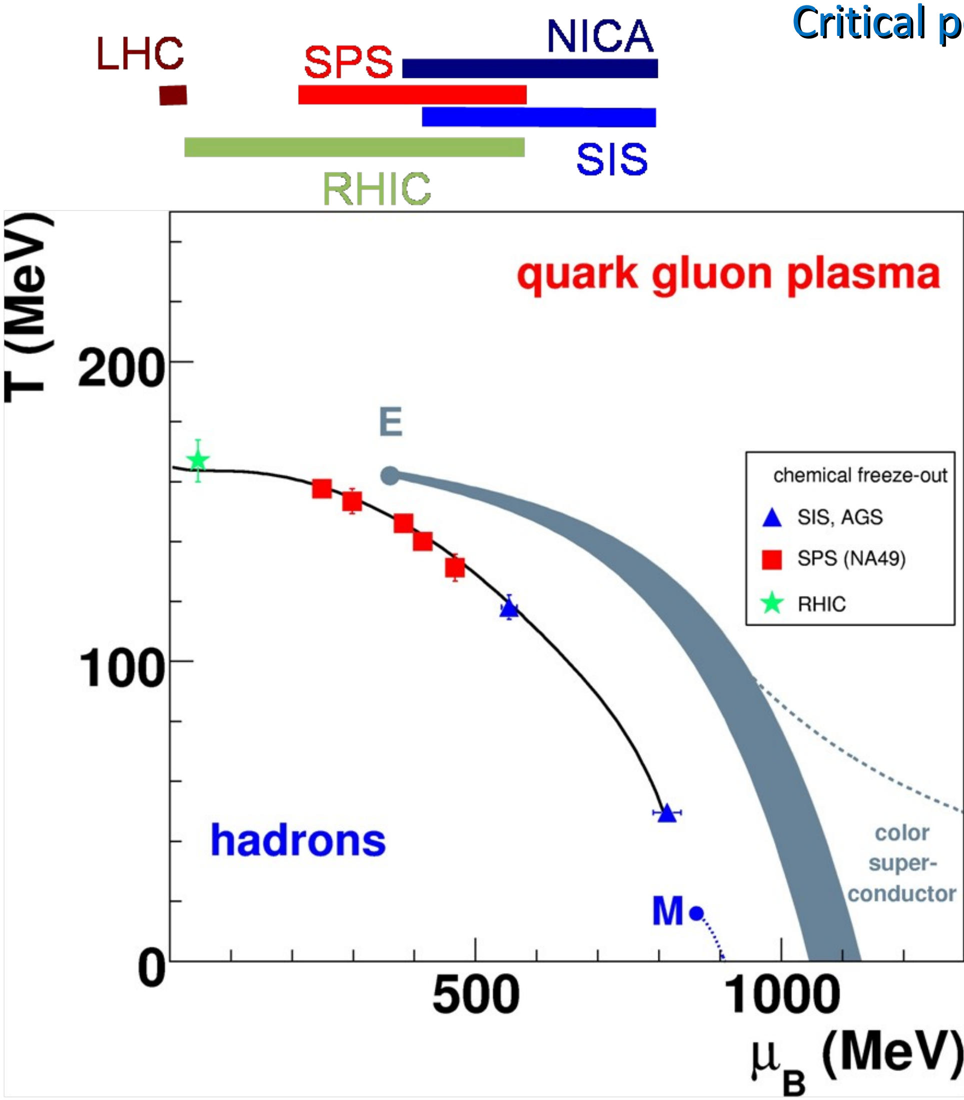
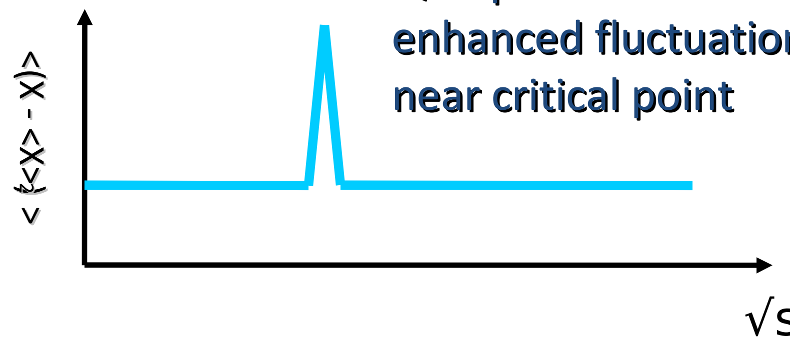
The Phase Diagram of QCD



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

QCD predicts enhanced fluctuations near critical point



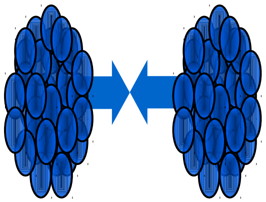
Experimental observations – look for

- 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

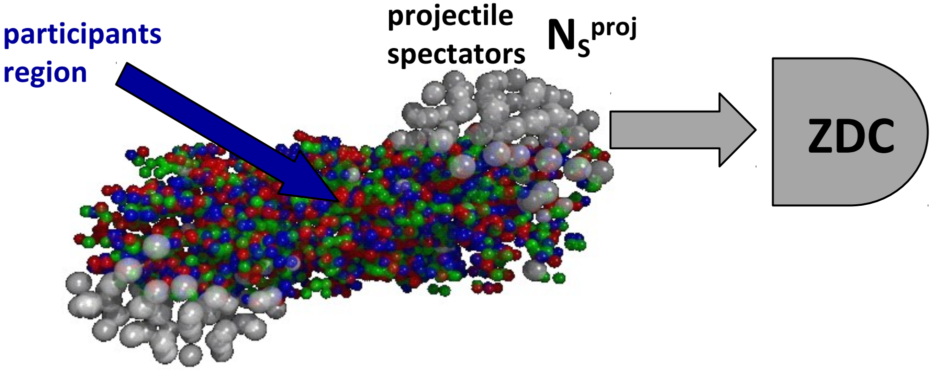
  - formation and decay of baryonic and mesonic resonances
  - string formation and decay

  (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

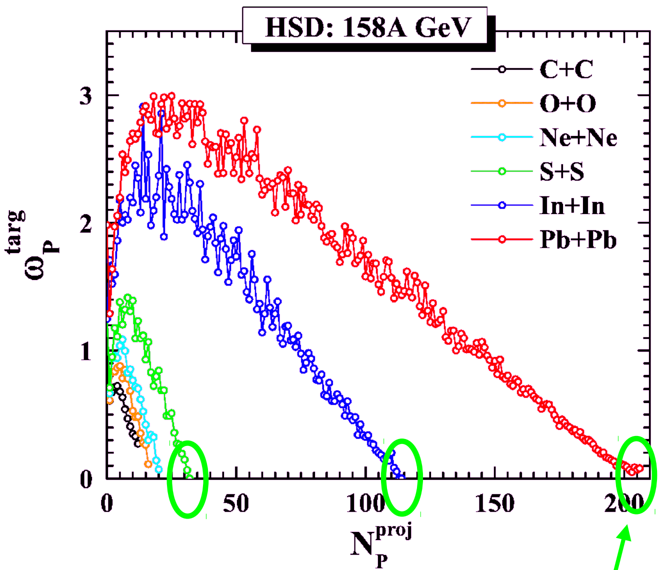


Participants number fluctuations **reflect in the observable fluctuations** (e. g. multiplicity fluctuations)

Projectile/target participants:

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

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

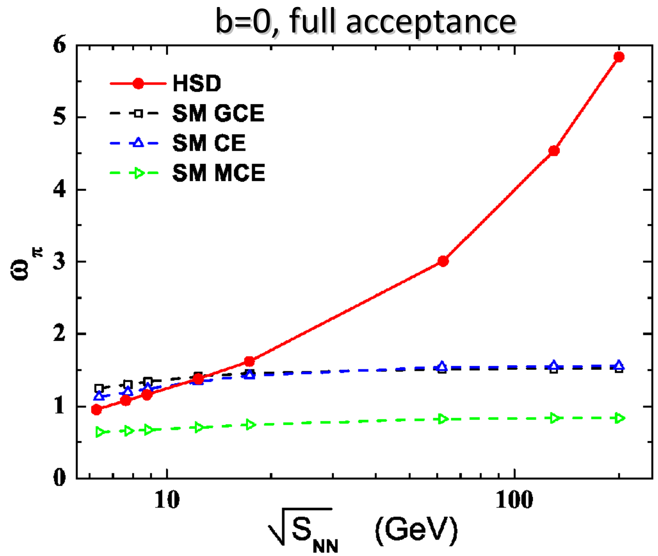


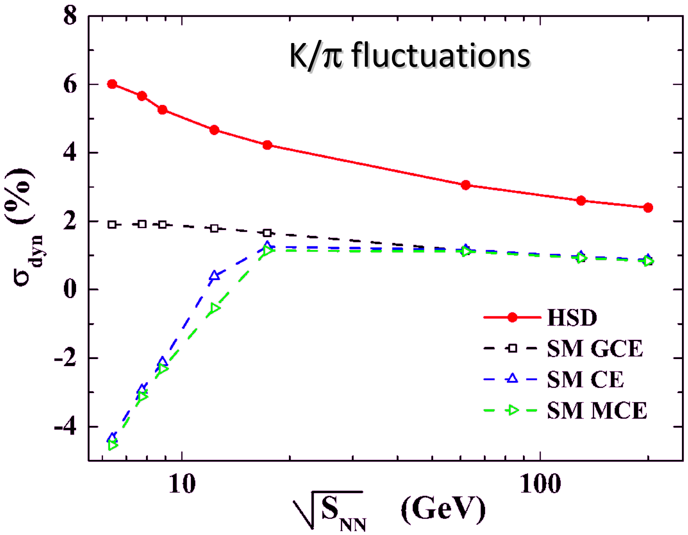
Even with fixed number of **projectile participants N_p^{proj}** the full number of participants N_p can fluctuate due to participant fluctuation in the **target N_p^{targ}**.

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:

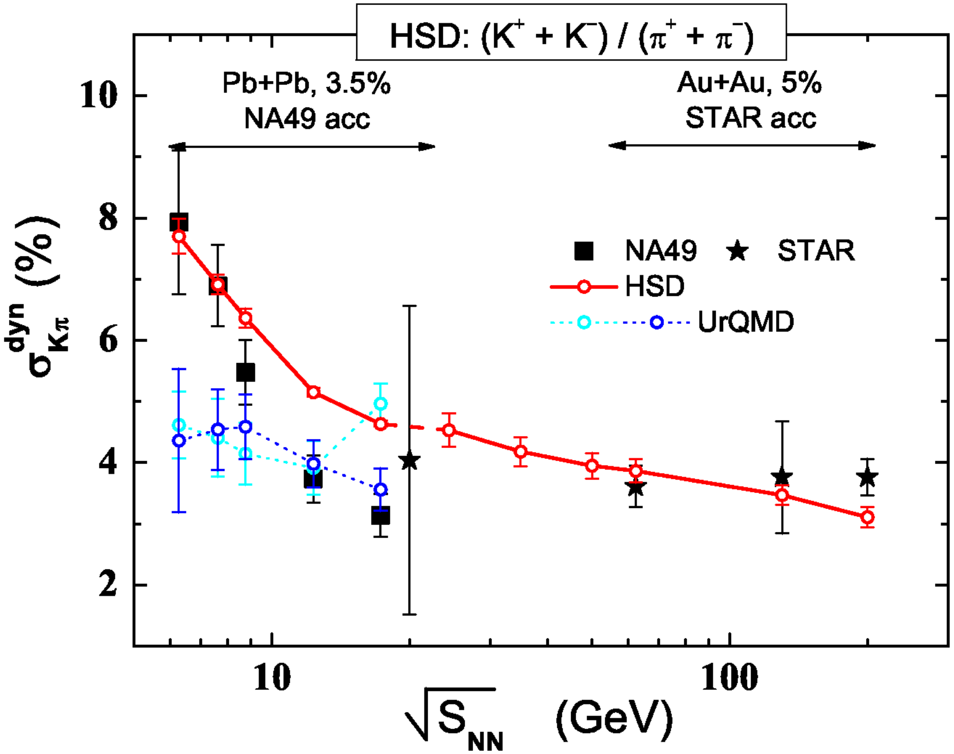
$$\sigma^2 \cong \frac{\omega_A}{\langle N_A \rangle} + \frac{\omega_B}{\langle N_B \rangle} - 2\rho_{AB} \left[\frac{\omega_A \omega_B}{\langle N_A \rangle \langle N_B \rangle} \right]^{1/2}$$

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.

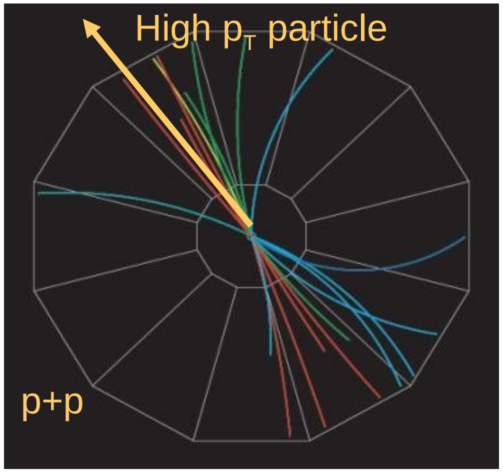
evidence for a critical point at low SPS energies ?

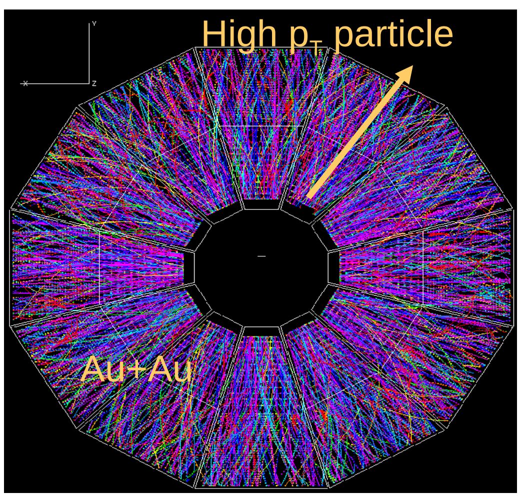
- But the HSD results shows the same behavior.

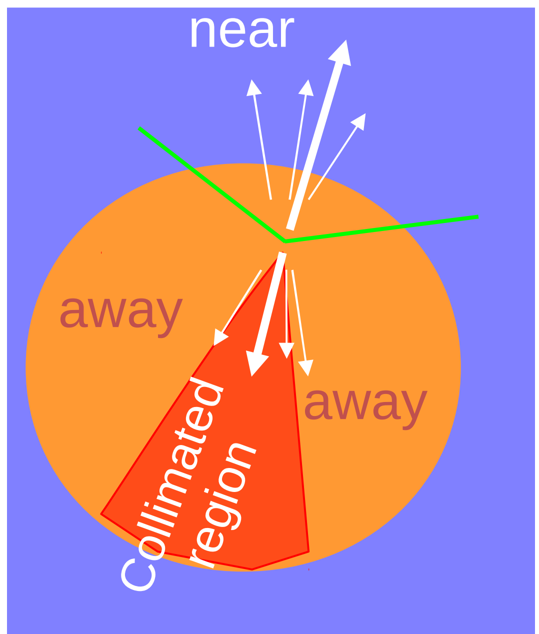
- K/π ratio fluctuations are driven by hadronic sources. No evidence for a critical point in the K/π ratio ?

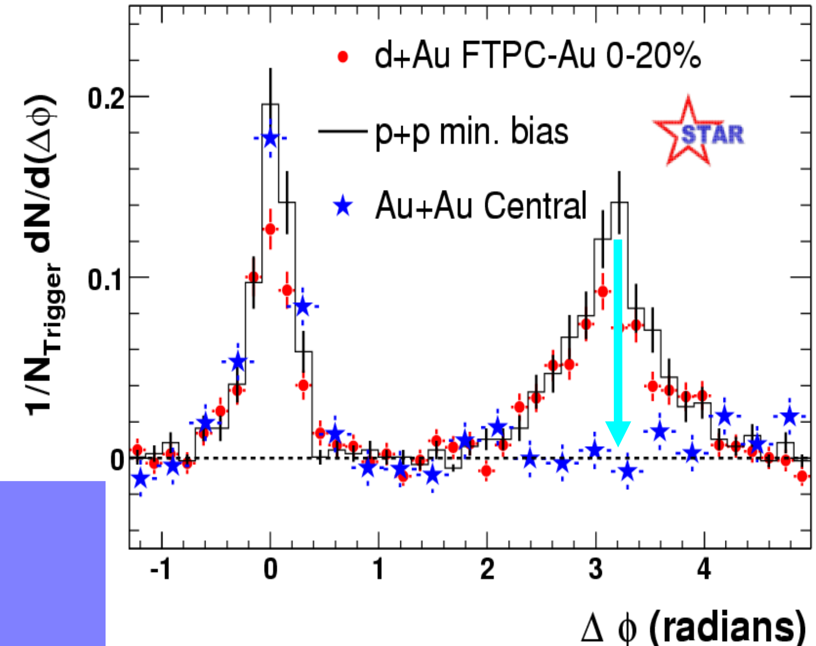
HSD: Phys. Rev. C 79 (2009) 024907
UrQMD: J. Phys. G 30 (2004) S1381, PoS CFRNC2006,017
NA49: 0808.1237
STAR: 0901.1795

Jet energy loss



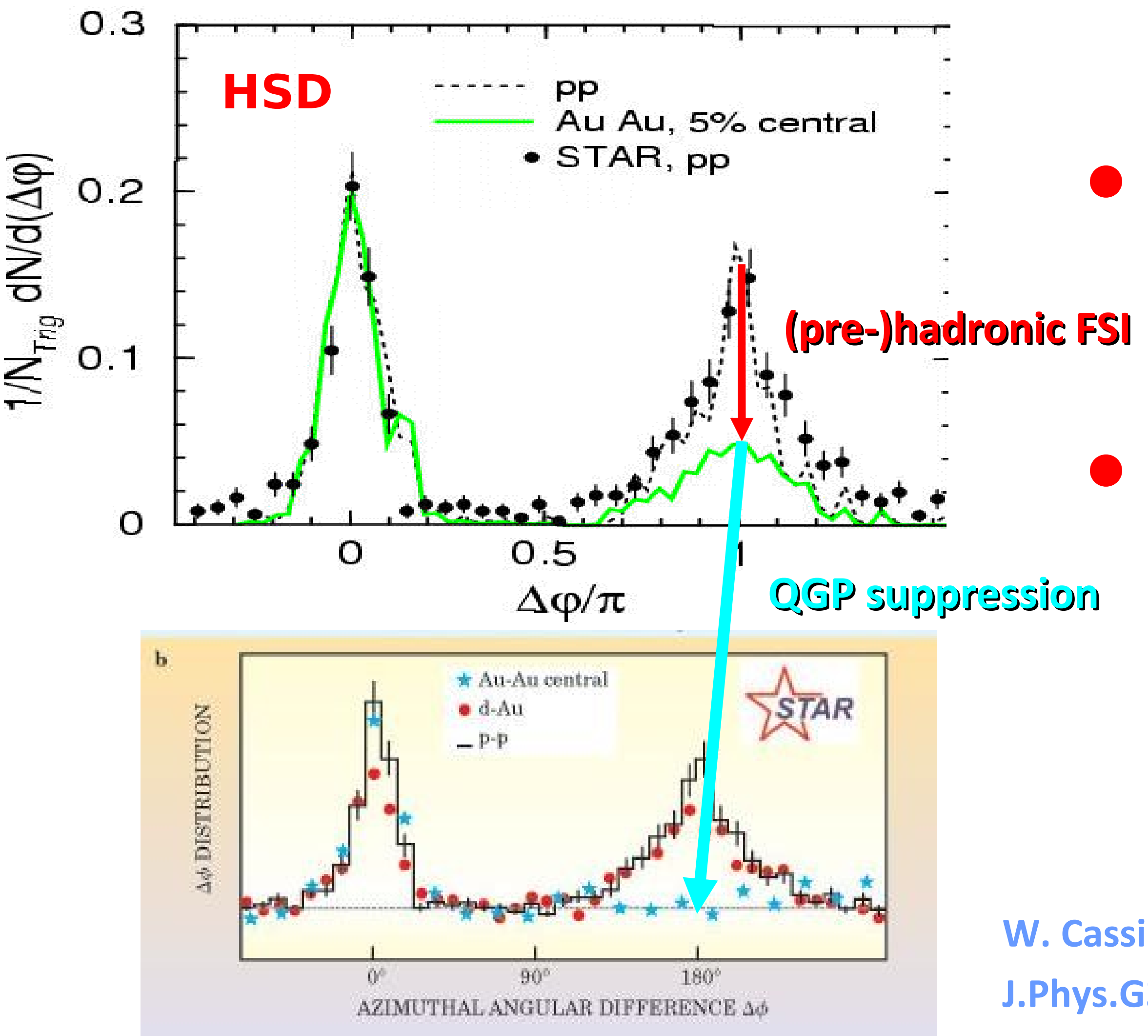






QGP suppression ?!

Jet suppression: dN/dφ (HSD)

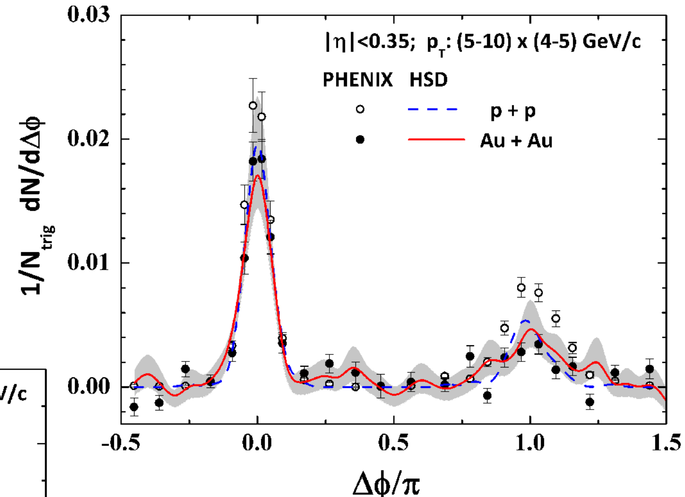


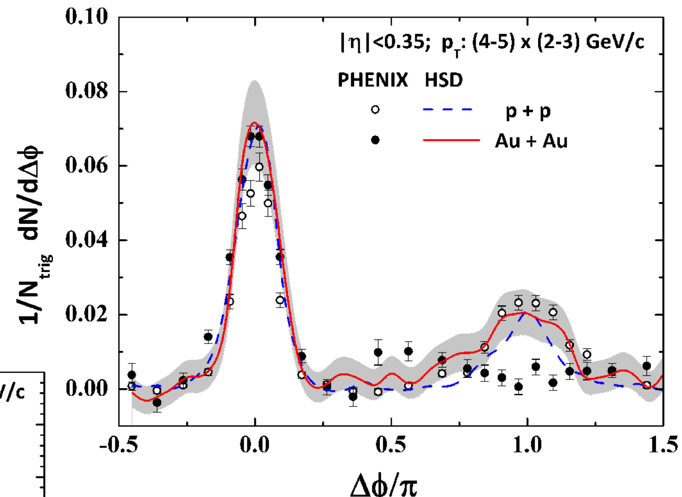
- The jet angular correlations for pp are fine!
- The near-side jet angular correlation for central Au+Au is well described, but the suppression of the far-side jet is too low!

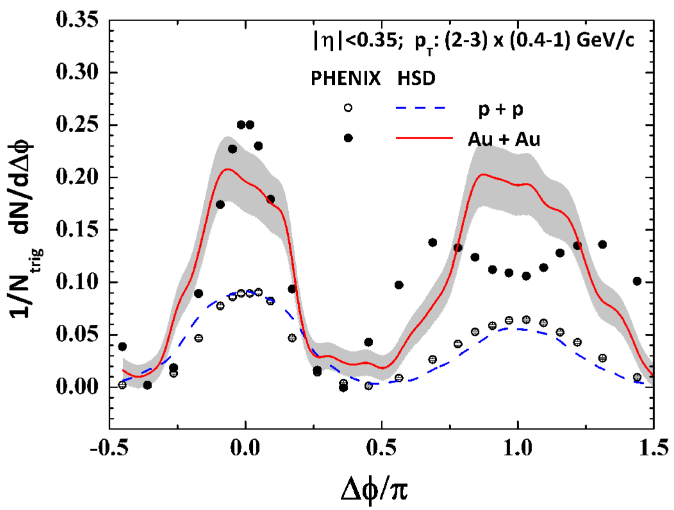
W. Cassing, K. Gallmeister and C. Greiner, J.Phys.G30 (2004) S801; NPA 748 (2005) 241

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.



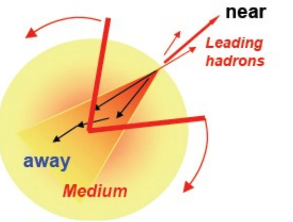




More energetic trigger particle

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

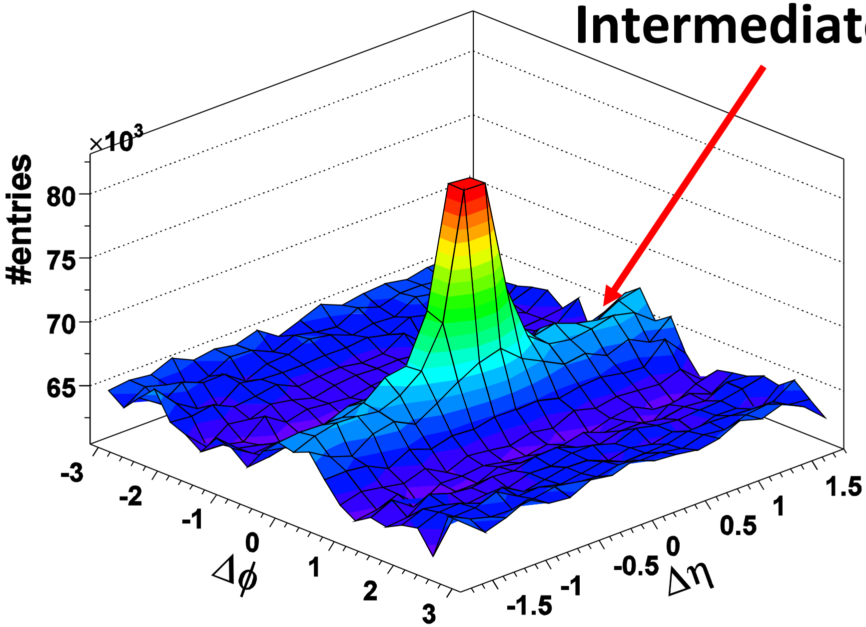


Fig. 1. (Color on-line) Preliminary associated particle distributions in $\Delta\eta$ and $\Delta\phi$ with respect to the trigger hadron for associated particles with 2 GeV$/c < p_T^{assoc} < p_T^{trig}$ in 0-12% central Au+Au collisions. Two different trigger p_T selections are shown: $3 < p_T^{trig}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

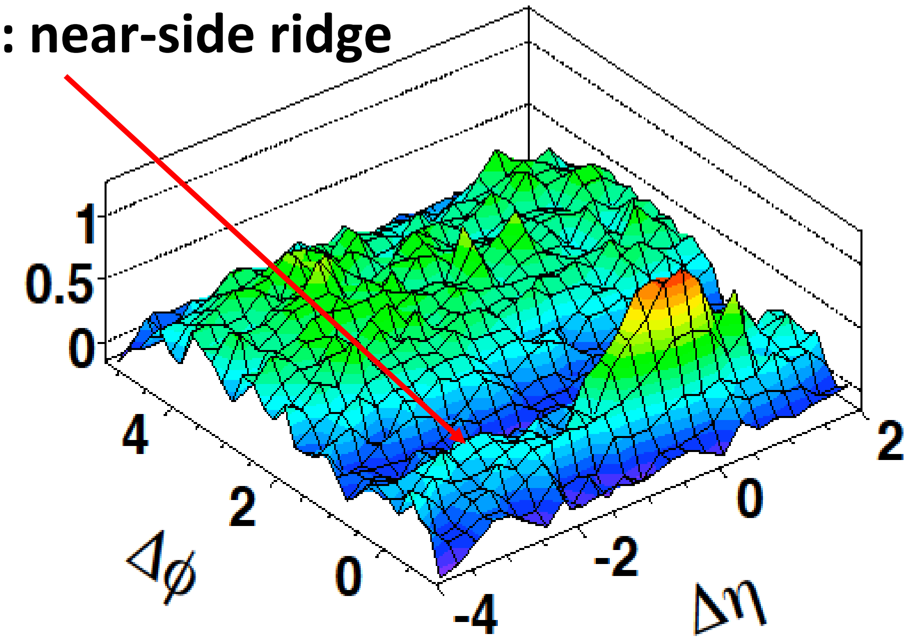
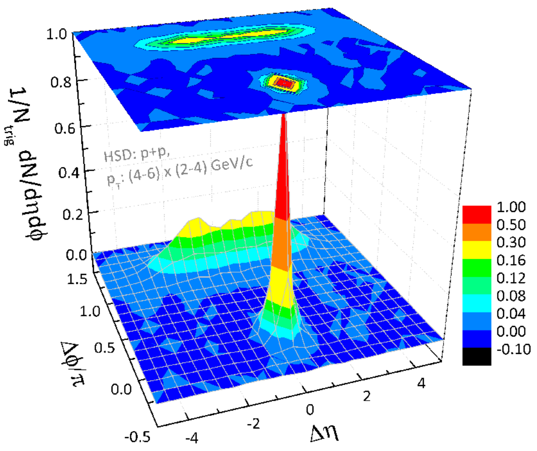


FIG. 2: (color online) Per-trigger correlated yield with $p_T^{trig} > 2.5$ GeV/c as a function of $\Delta\eta$ and $\Delta\phi$ for $\sqrt{s}$ and $\sqrt{s_{NN}}$=200 GeV (a) PYTHIA p+p and (b) PHOBOS 0-30% central Au+Au collisions. (c) Near-side yield integrated

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

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

p+p

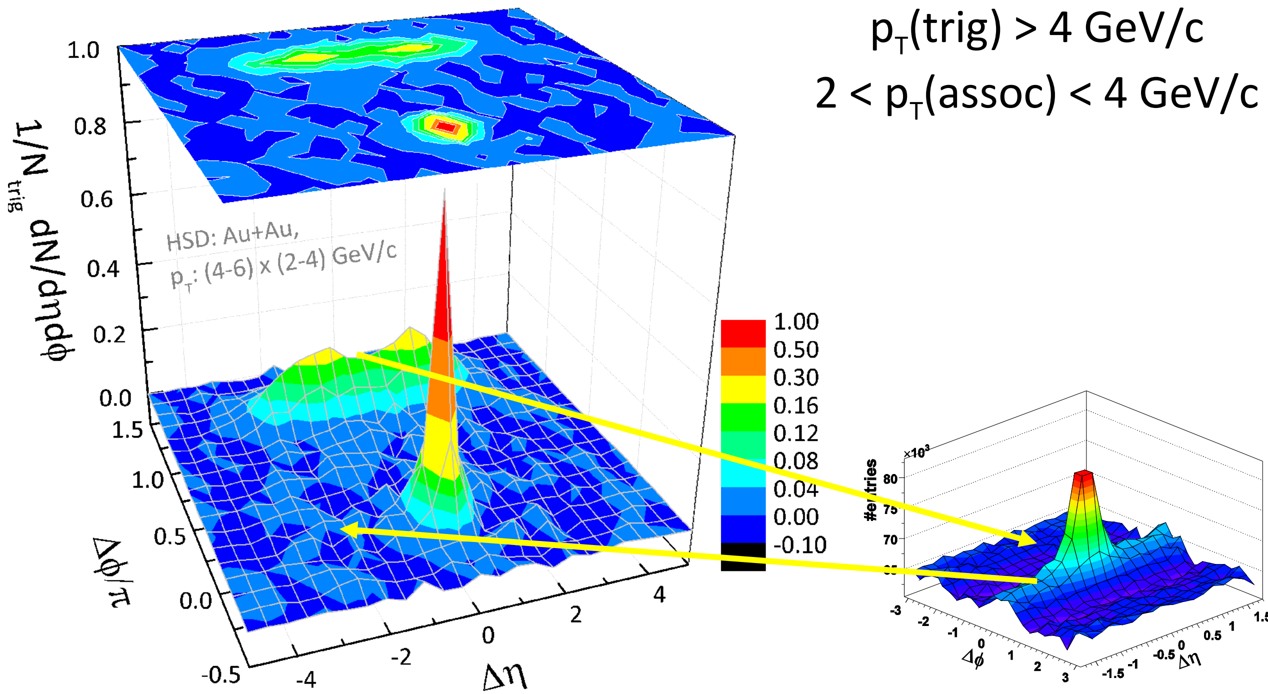


Au+Au

STAR: High p_T:

p_T(trig) > 4 GeV/c

2 < p_T(assoc) < 4 GeV/c



STAR

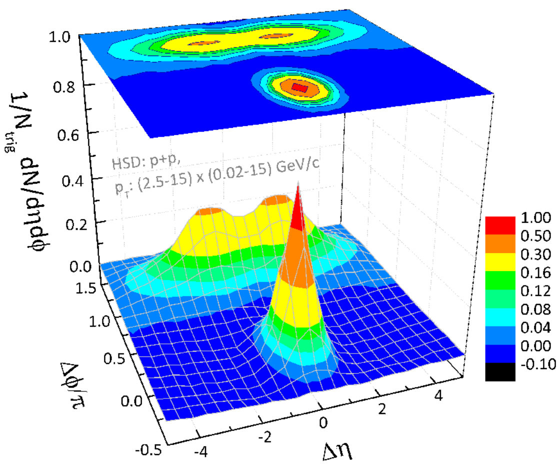
HSD vs. STAR:

- 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

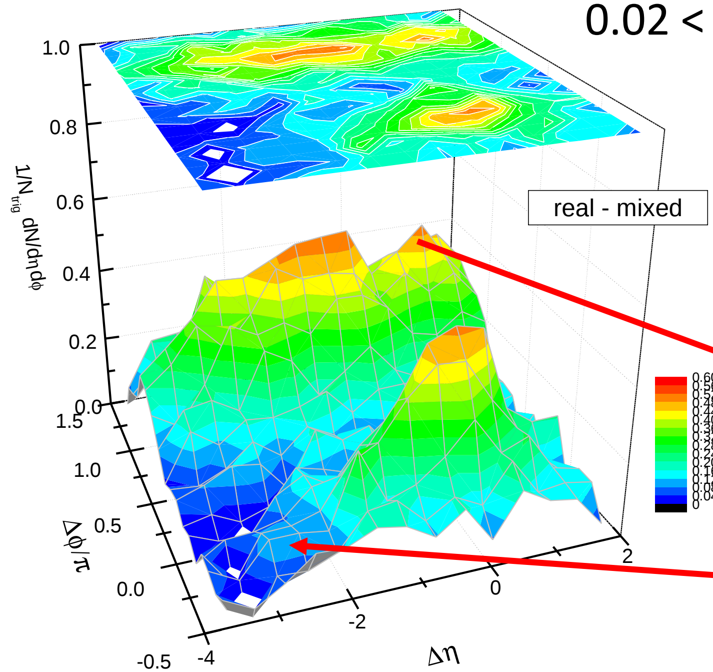


PHOBOS: Intermediate p_T:

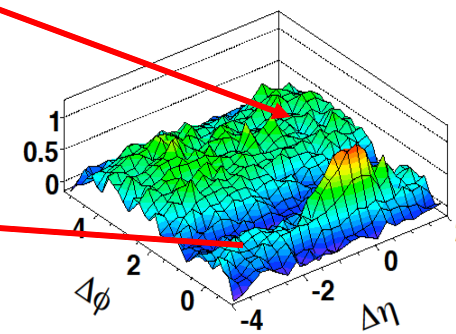
p_T(trig) > 2.5 GeV/c;

0.02 < p_T(assoc) < 2.5 GeV/c

Au+Au



PHOBOS



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:

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Jaakko Manninen

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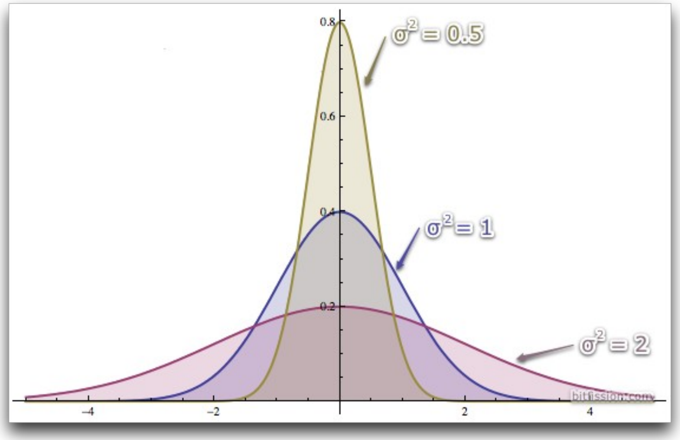
HSD

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)

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

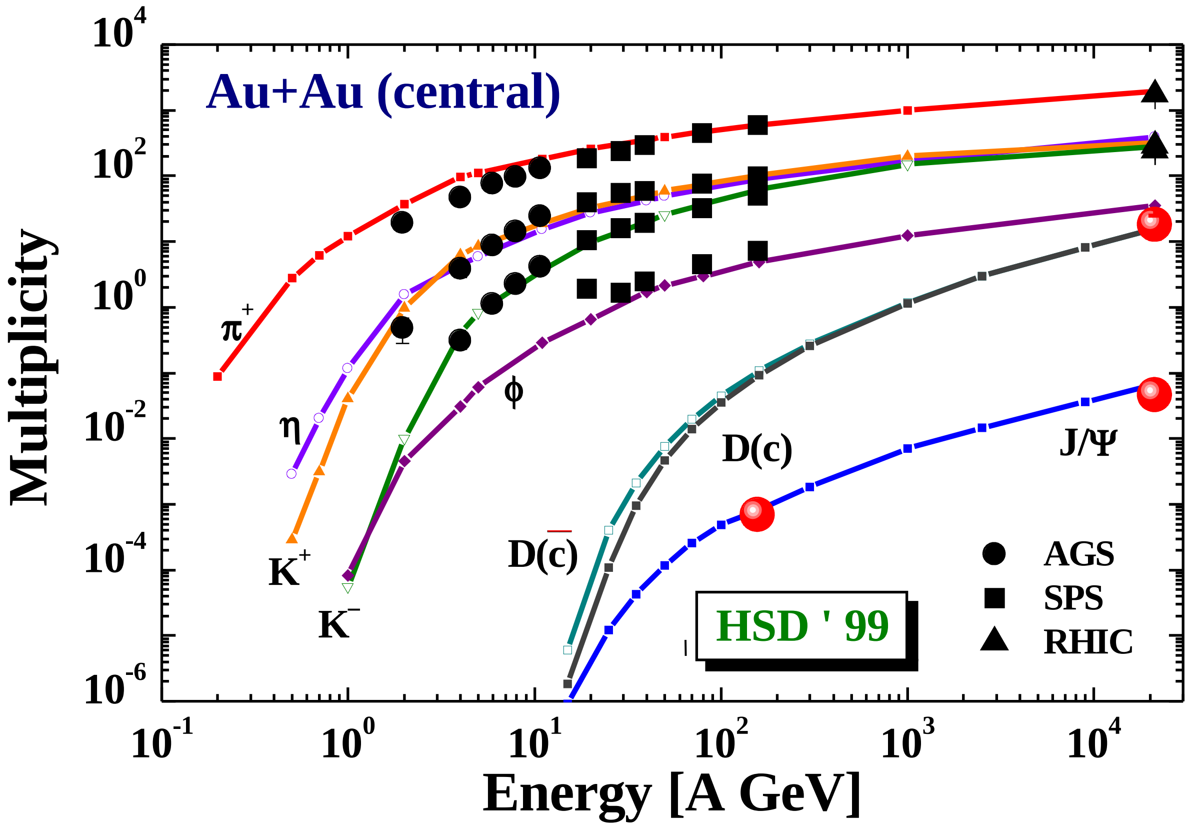
- Correlations between different species in the acceptance

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

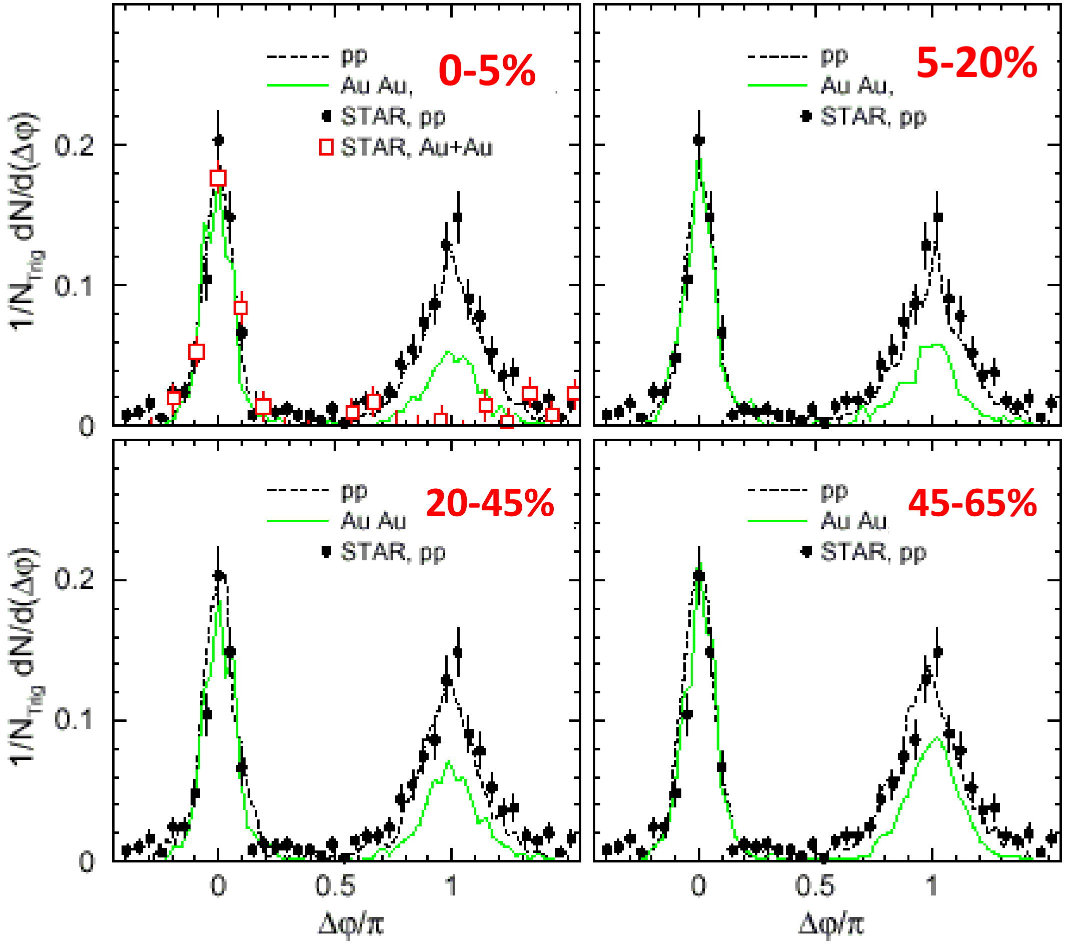
- Correlations between multiplicities in different acceptance intervals
- Skewness and kurtosis

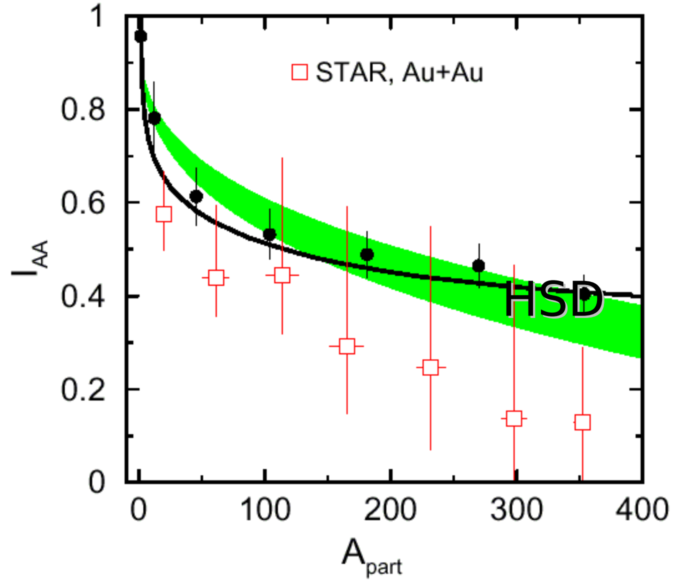
HSD – a microscopic model for heavy-ion reactions

- 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





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

Missing suppression of far-side jet in central reactions!

Near-side jet is unchanged for all centralities

W. Cassing, K. Gallmeister

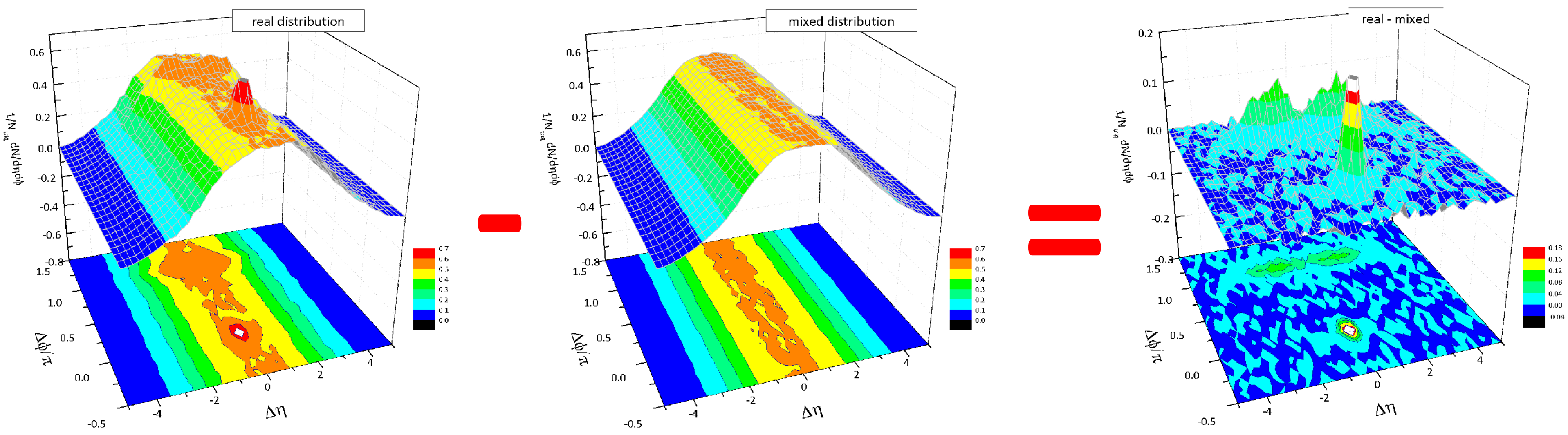
NPA 748 (2005) 241

Background subtraction for Au+Au collisions

Real distribution

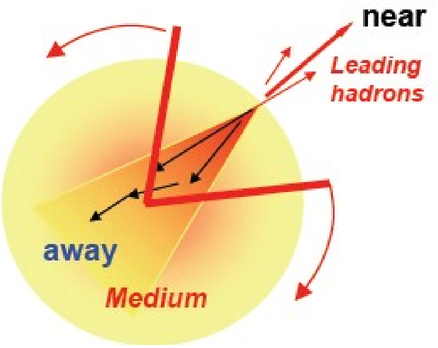
Mixed distribution

Real-Mixed distribution

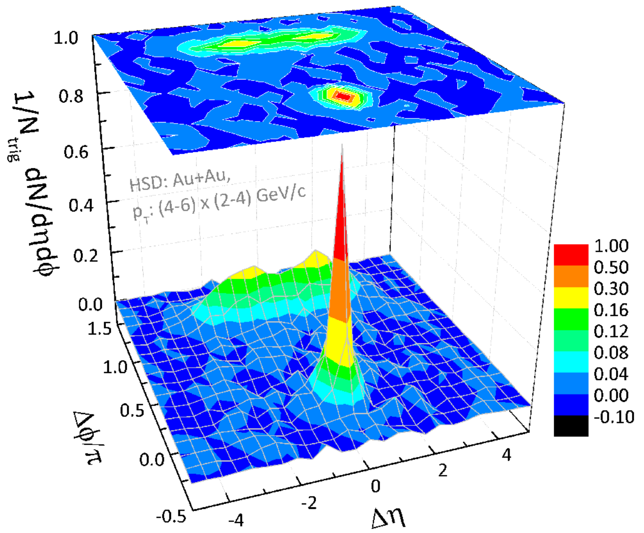


- **Background can mask the signal and should be subtracted. Especially for soft p_T cuts when there are a lot of bulk particles in the associative p_T region.**

Summary



- **The near-side ridge structure is NOT seen in HSD:**



The **near-side ridge** in the wide range of pseudorapidity $\Delta\eta$ seen in the experimental data from the STAR and PHOBOS collaborations **is not reproduced by hadron-string dynamics**

- **Jet suppression signals of QGP:**

Observed very strong **far-side jet suppression** is NOT reproduced in the hadron-string picture

=> evidence for strong nonhadronic interactions in the early phase of the reaction!