Fluctuating initial conditions in hydrodynamics for two-particle correlations

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ISMD2010, University of Antwerp - Antwerp, Belgium

Outline

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1. Introduction
   - Initial Conditions in Hydrodynamic Approach
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4. Mechanism of ridge formation in hydrodynamics
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5. Summary

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Initial Conditions in Hydrodynamic Approach

In hydrodynamic approach of nuclear collisions, it is assumed that, after a complex process involving microscopic collisions of nuclear constituents, at a certain early instant a hot and dense matter is formed, which would be in local thermal equilibrium. This state is characterized by some initial conditions (IC), usually parametrized as smooth distributions of thermodynamic quantities and four-velocity.

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Previous Studies

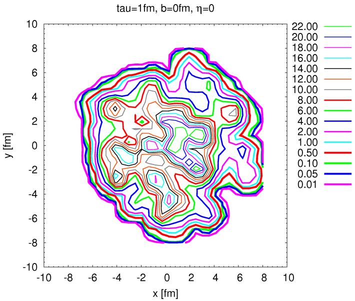
In previous works, we introduced fluctuating IC in hydrodynamics, by using NEXUS event generator (H.J. Drescher et al., Phys. Rev. C65 (2002) 054902.), and showed important effects on several observables:

- p_T distributions
- η- and p_T-dependences of v_2
- Fluctuations of v_2
- HBT radii

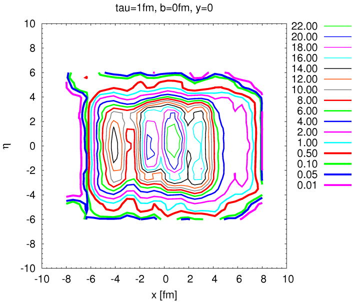
NEXUS Fluctuating Initial Conditions

Energy density distribution (Au+Au at 200 A GeV)

in a transverse plane



in a longitudinal plane



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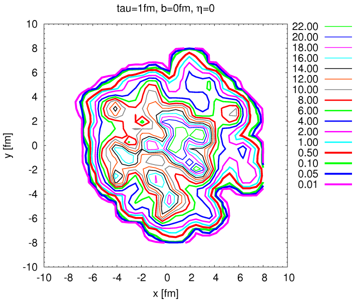

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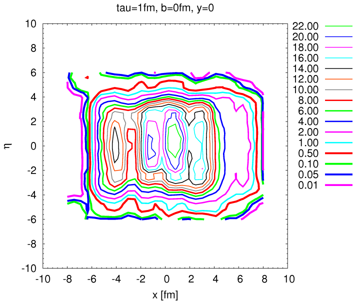

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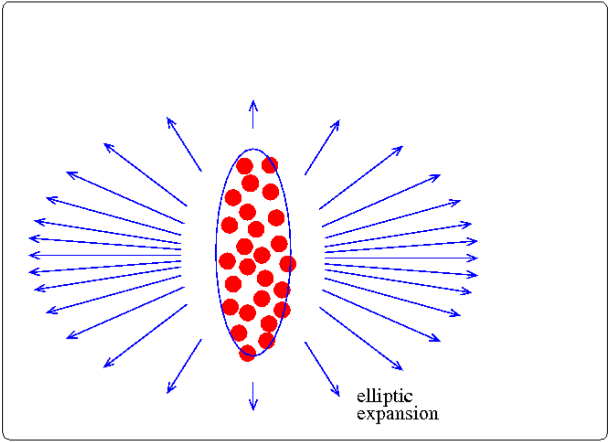

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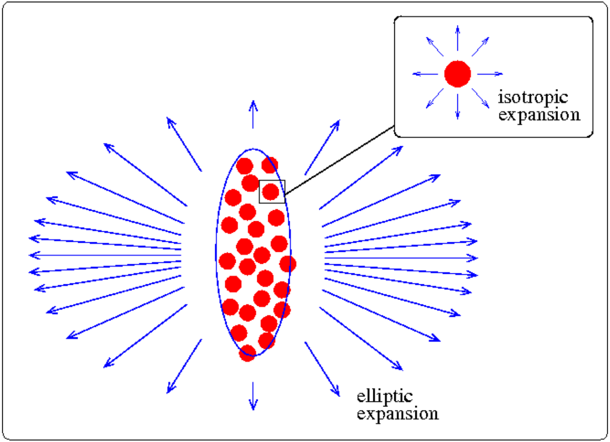
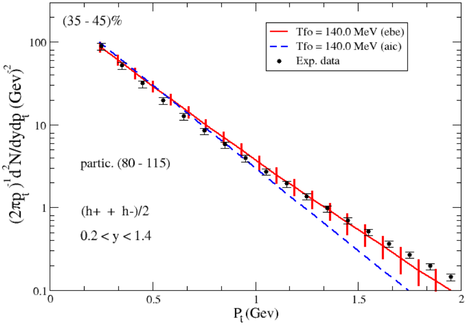


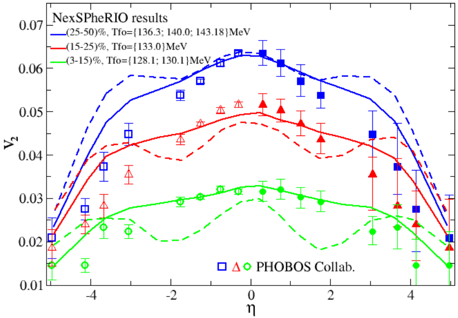
p_T distribution



Y.H *et al.*, Acta Phys. Polon. B**40** 931 (2009)

Data: PHOBOS Collab., B.B. Back *et al.* Phys.Lett. B**578** 297 (2004)

$< v_2 > (\eta)$



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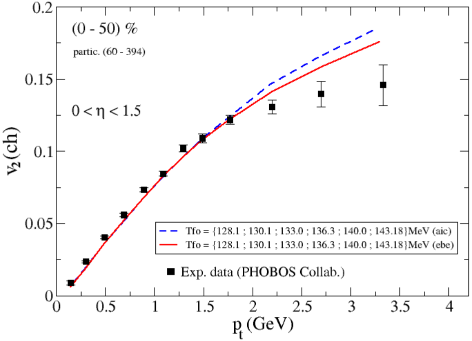

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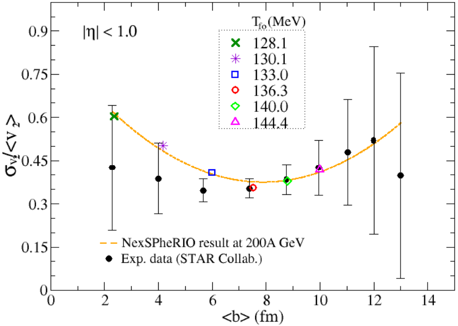
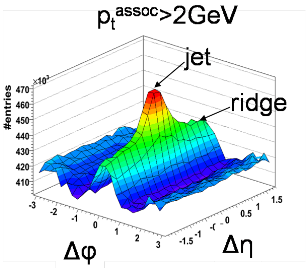
$\sigma_{v_2} / < v_2 >$



Y.H *et al.*, Phys.Atom.Nuclei **71** 1588 (2008)

Data: P. Sorensen [STAR Collab.], QM 2006, nucl-ex/0612021

What is ridge effect?



- Ridge Effect has been observed in long-range two-particle correlation.
- The main characteristic is a narrow $\Delta\phi$ and wide $\Delta\eta$ correlation around the trigger.
- There is also some awayside stucture: one or two ridges.
- Originally, the trigger was chosen a high-p_T presumably jet particle, but now data are available also for low-p_T trigger or no-trigger.

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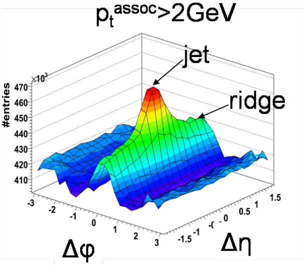

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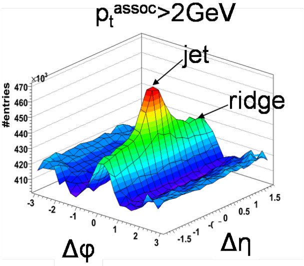

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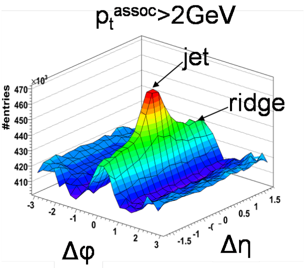

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Ridge Effect in Hydrodynamic Approach

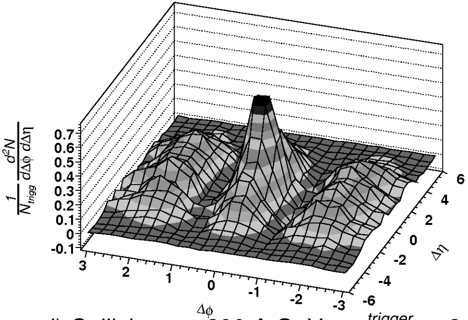
Our recent research* seems to indicate that also the description of the ridge effect requires event-by-event fluctuating tubular initial conditions.

* J. Takahashi, *et al.*, PRL 103 (2009) 242301
Y. Hama, *et al.*, Nonlin. Phenom. Complex Sys. 12 (2010) 466
R.P.G. Andrade, *et al.*, J. Phys. G37 (2010) 094043
R.P.G. Andrade, *et al.*, Nucl. Phys. A (2010) in press
R.P.G. Andrade, *et al.*, arXiv: 1008.4612 [nucl/th]

See also Rone Andrade's talk (Friday, 24/09).

Ridge Effect in Hydrodynamic Approach

In a previous work (J.Takahashi, *et al.*, PRL 103 (2009) 242301), we got the ridge structure in a purely hydrodynamic model.



Au+Au (Central) Collisions at 200 A GeV $p_T^{trigger} > 2.5 GeV$, $p_T^{assoc.} > 1 GeV$

Outline

Which is the origin of ridges?

Y.H. et al., Nonlin.Phenom.Complex Syst. **12** 466 (2009); arXiv:0911.0811;
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Since each event in our model presents IC with many high-energy tubes, one may associate these tubes + transverse expansion with the ridge structure.

However, the phenomenon is not so trivial.

Besides, why away-side ridges?

Considering mainly the central collisions we tried to understand the origin of the ridge structure, especially the away-side one.

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How we study the origin of the ridge structure

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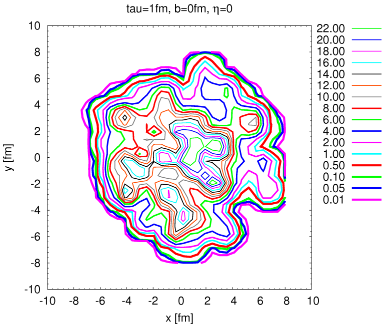

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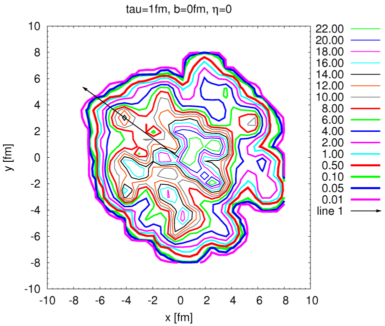

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- Replace the complex background by a smooth one (average IC).

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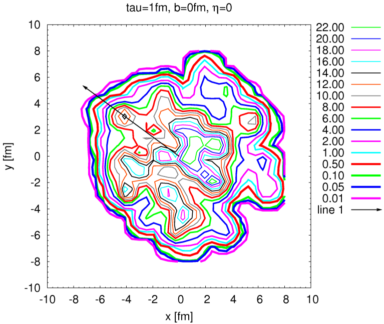

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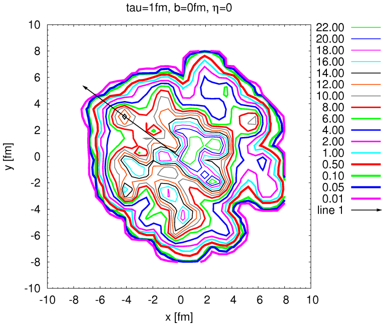

- To study closely what happens in the neighborhood of a tube near the surface of the hot matter.
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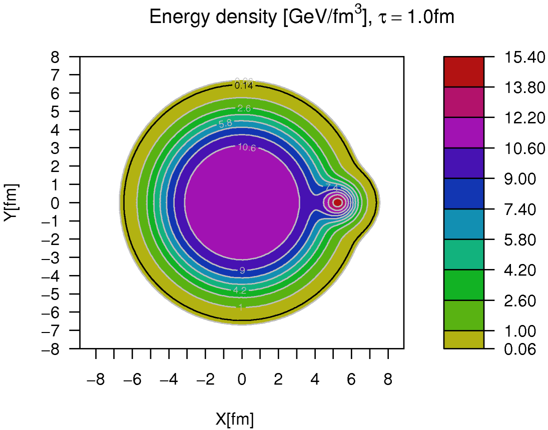
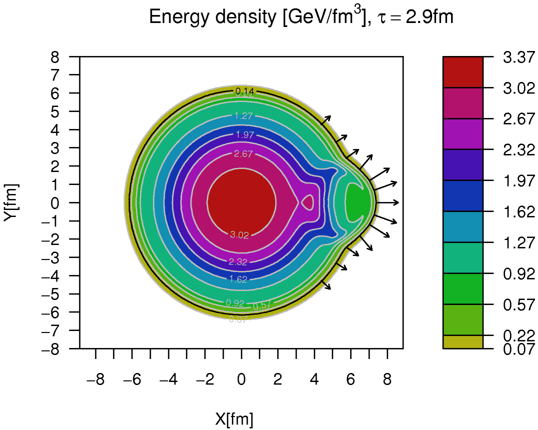
- one-tube model with boost-invariant longitudinal expansion.

Outline

Time evolution of a tube + the average background

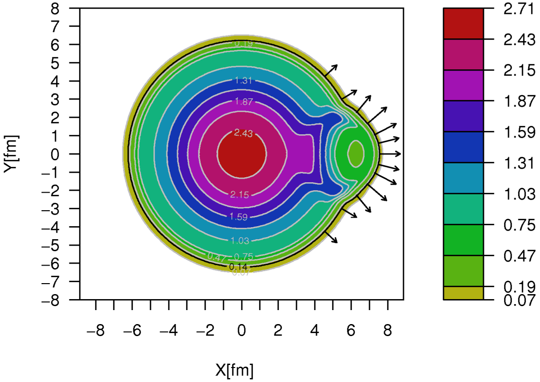


Time evolution of a tube + the average background



Time evolution of a tube + the average background

Energy density [GeV/fm^3], $\tau = 3.5$fm



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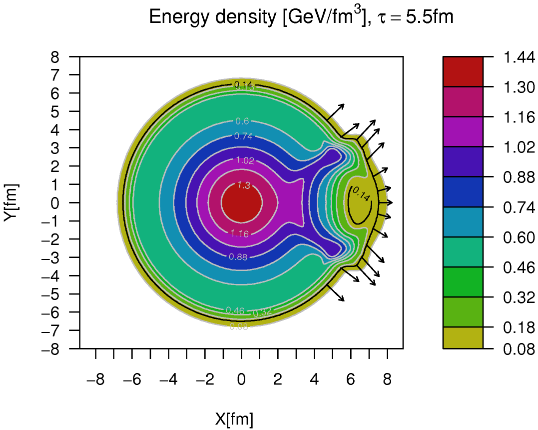

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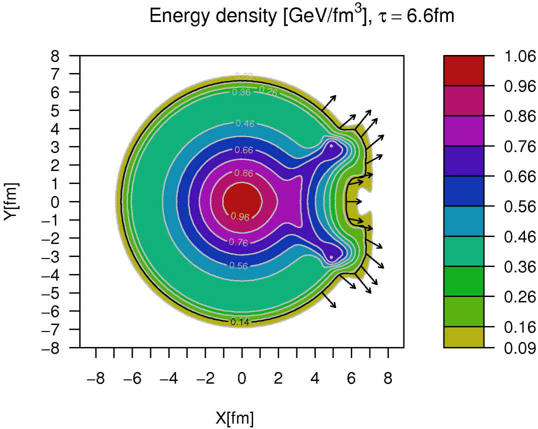

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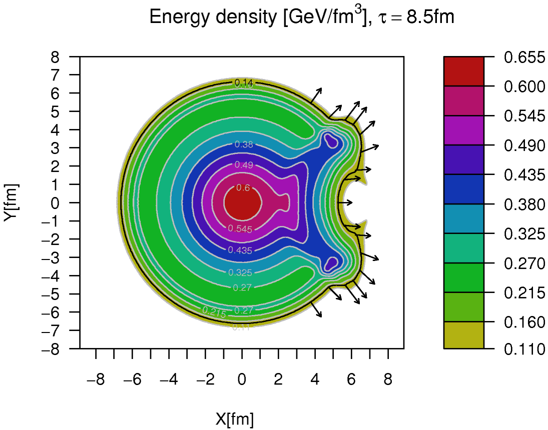

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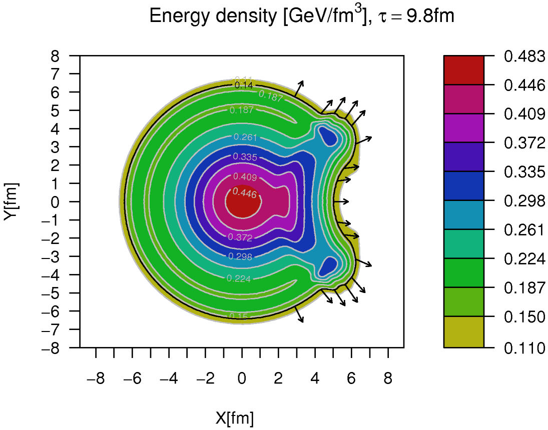

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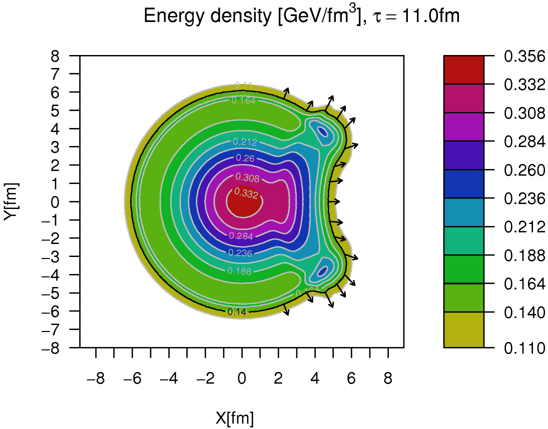

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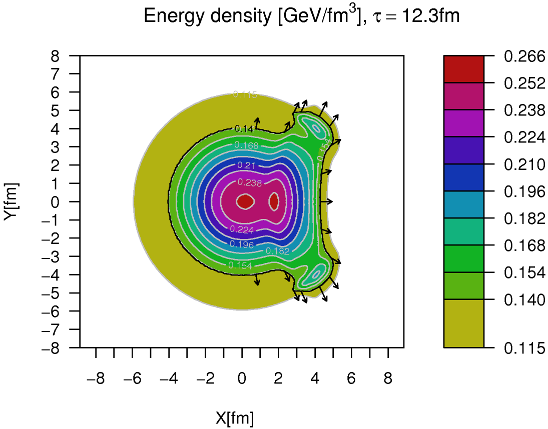

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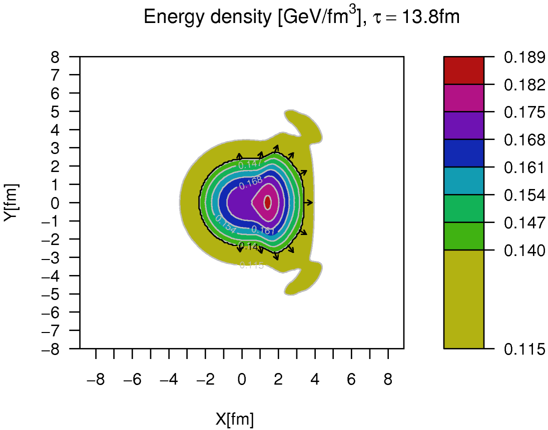
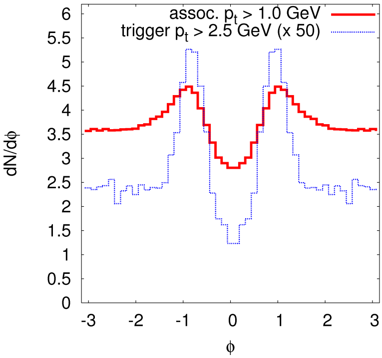
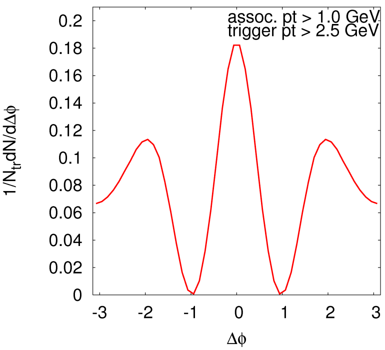


ϕ distributions (left) and two-particle correlation (right) produced by a tube + the average background





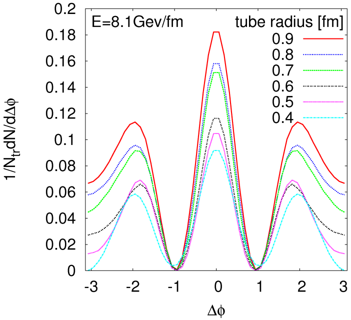
Outline

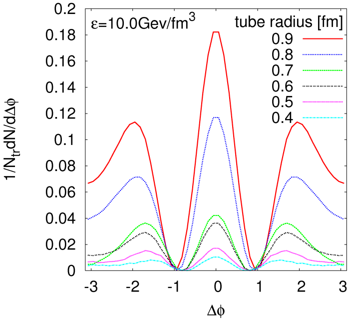
Parameter dependence

In [Y.H. et al., Nonlin.Phenom.Complex Syst. **12** 466 (2009); arXiv:0911.0811;], we studied the dependence on several parameters.
Some parameters seem to be of fundamental importance, while others are not.
In the following we show effects of two of the important parameters. They are

- energy of the tube ($\propto \epsilon \times r^2$);
- position of the tube.

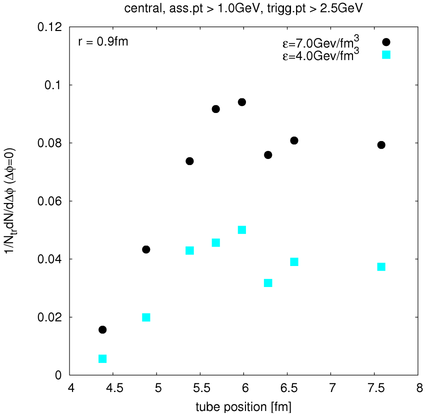
Parameter dependence - tube energy





Position of the tube: $R = 5.38\,\mathrm{fm}$

Parameter dependence - tube position



Here, it is seen that there is a critical radial position above which two-particle correlation due to a tube is more or less stable, and below which it disappears quickly. Thus, we can neglect tubes which are deep inside the hot matter.

Summary

- The initial conditions in heavy-ion collisions should have important event-by-event fluctuations and also they should be very bumpy.
- Such bumpy IC affects several observables (p_T distributions, η- and p_T-dependences of v_2, v_2 fluctuations, etc.) in important amount.
- Hydrodynamic expansion starting from fluctuating IC with tubular structure produces ridge structure in the 2-particle correlation.
- NeXSPheRIO code can reproduce several observed characteristics of ridges.

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Summary

- A high-density tube, close to the surface of the hot matter, causes flow with two maxima in azimuth, symmetrical with respect to the tube position.
- Such a flow implies a near-side peak and double, symmetrical away-side peaks in $\Delta\phi$ in the 2-particle correlation, with respect to the high-p_T trigger.
- The shape of 2-particle correlation curve is more or less stable in a wide range of parameters.
- The intensity of the correlation depends strongly on the energy content of the tube and its position.

More details will be given in Rone Andrade's talk (Friday, 24/09).

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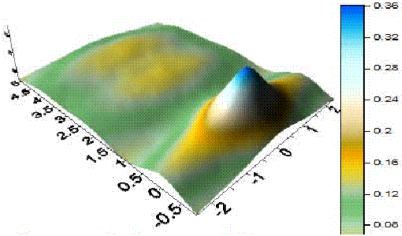
Outlook - (2+1)-particle Correlations

These are also three-particle correlations, but the first associated particle is fixed with respect to the trigger.

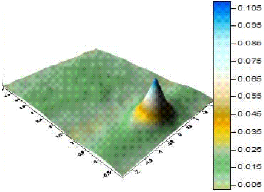
For example,
in the centrality (30-40%) window, our result for the two-particle correlation shows a peak at $\Delta\eta = 0$ and $\Delta\phi = 0$.



What is this?

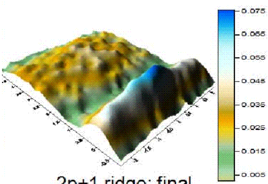
Outlook - (2+1)-particle Correlations

(2+1)-particle correlation as function of $\Delta\eta_{t2}$ and $\Delta\phi_{t2}$



2p+1 jet: final

$\Delta\eta_{t1} < 0.2$

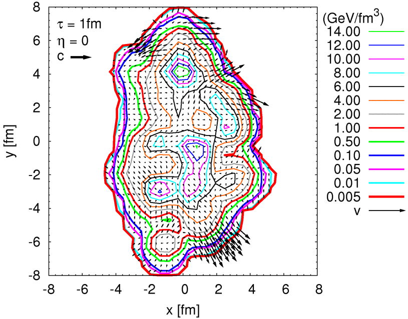


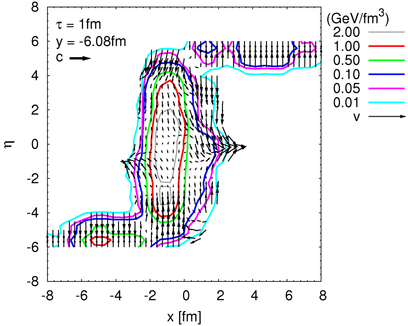
2p+1 ridge: final

$\Delta\eta_{t1} > 1.5$

Thermalized jets

Nexus produces jets, but they are thermalized together with the bulk matter in SPheRio.





Event-averaging effects

For realistic fluctuating events, any distribution has a rather complicated aspect. Averaging over events cancels the interference terms making it smooth.

PHENIX data

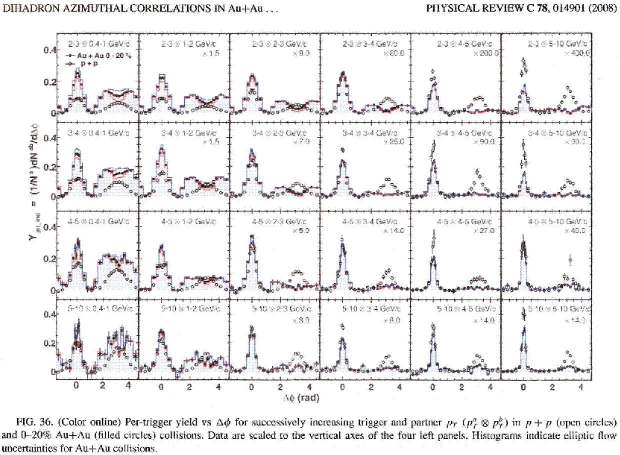


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FIG. 36. (Color online) Per-trigger yield vs $\Delta\phi$ for successively increasing trigger and partner p_T ($p_T^a \otimes p_T^b$) in $p+p$ (open circles) and 0–20% Au+Au (filled circles) collisions. Data are scaled to the vertical axes of the four left panels. Histograms indicate elliptic flow uncertainties for Au+Au collisions.

[PHENIX Collaboration, A.Adare et al., *Phys. Rev.* **C78** (2008) 014901-1]

STAR data

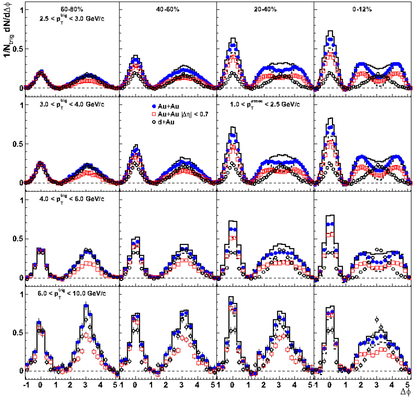

FIG. 2: Background-subtracted azimuthal angle difference distributions for associated particles with p_T between 1.0 and 2.5 GeV/c and for different ranges of trigger particle p_T, ranging from $2.5 - 3.0$ GeV/c (top row) to $6 - 10$ GeV/c (bottom row). Results are shown for Au+Au collisions (solid circles) with different centrality (columns) and d+Au reference results (open circles). The rapidity range is $|\eta| < 1$ and as a result the rapidity-difference $|\Delta\eta| < 2$. Open red squares show results for a restricted acceptance of $|\Delta\eta| < 0.7$, using tracks within $|\eta| < 1$. The solid and dashed histograms show the upper and lower range of the systematic uncertainty due to the v_2 modulation of the subtracted background.

(M.M.Aggarwal et al.,