On the origin of the trigger-angle dependence of the ridge structure

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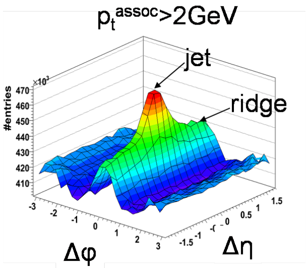
What is ridge effect?



- 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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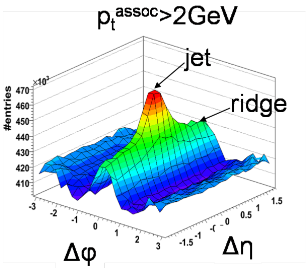

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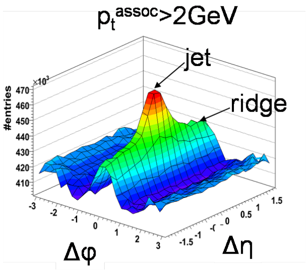

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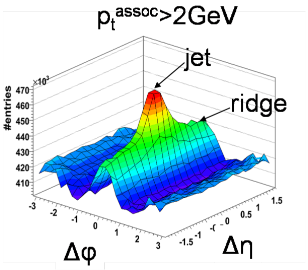

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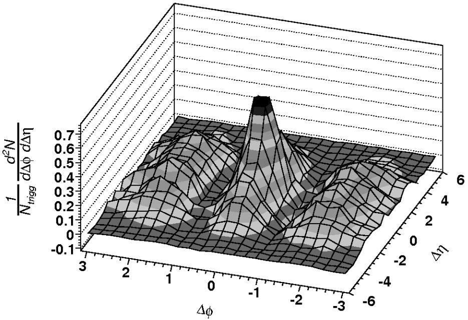
Ridge effect in hydrodynamic approach

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 $\quad p_T^{trigger} > 2.5GeV,\ p_T^{assoc.} > 1GeV$

Ridge effect in hydrodynamic approach

What is essential to producing ridges in hydrodynamic approach are

- Event-by-event fluctuating initial conditions (IC) and besides
- Very bumpy tubular structure in the IC.

Nowadays, this kind of IC are being studied by several groups.

We have been using NEXUS event generator (H.J. Drescher et al., Phys. Rev. C65 (2002) 054902.) for producing such fluctuating IC.

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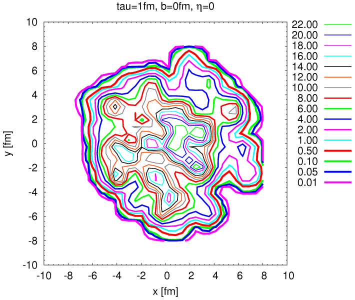
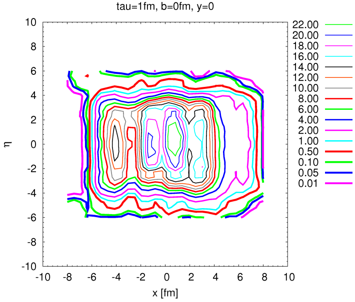
NEXUS fluctuating initial conditions

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

in a transverse plane



in a longitudinal plane



Outline

Some previous results

Our previous results can be seen in the following papers:

1. J. Takahashi, *et al.*, PRL 103 (2009) 242301
2. Y. Hama, *et al.*, Nonlin. Phenom. Complex Sys. 12 (2010) 466
3. R.P.G. Andrade, *et al.*, J. Phys. G37 (2010) 094043
4. R.P.G. Andrade, *et al.*, Nucl. Phys. A**854** (2011) 81
5. R.P.G. Andrade, *et al.*, arXiv: 1008.4612 [nucl/th]
6. Y. Hama, *et al.*, arXiv: 1012.1342 [hep/ph]
7. R.P.G. Andrade, *et al.*, arXiv: 1012.5275 [hep/ph]

Some previous results

In some of these papers, we have shown results of 3D hydro calculations, starting from NEXUS events, obtaining some of the experimentally known properties such as

- centrality dependence (2., 3. and 4.)
- trigger-direction dependence in non-central windows (2., 3., 4. and 7.)
- p_T dependence (3. and 4.)

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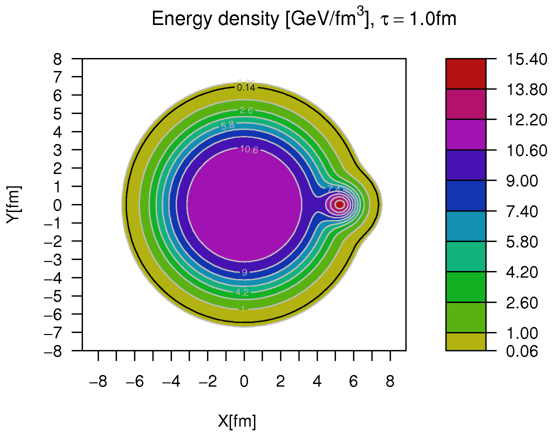
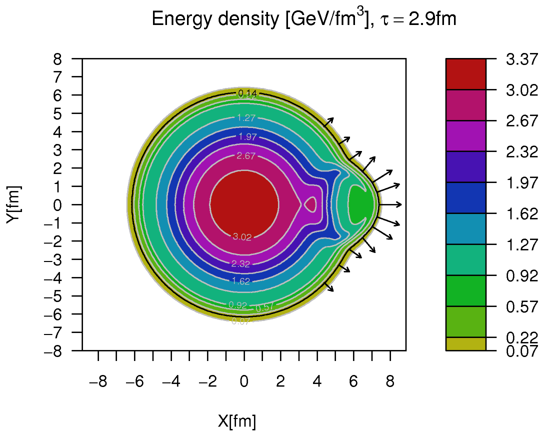
One-tube model

In order to understand the dynamics of ridge formation, we studied carefully what happens in the neighborhood of a peripheral high-energy tube, introducing what we call boost-invariant one-tube model (2.)

One-tube model: IC (central collision)



Time evolution of a tube + the average background



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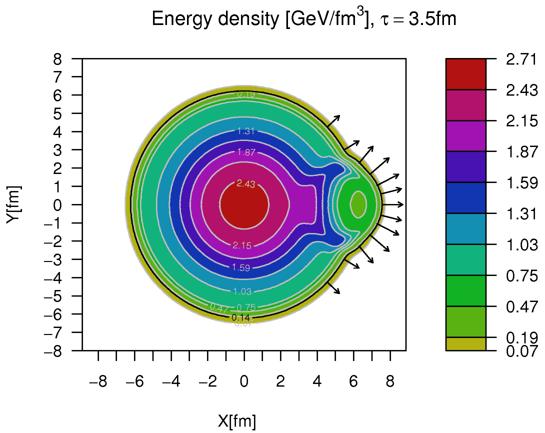

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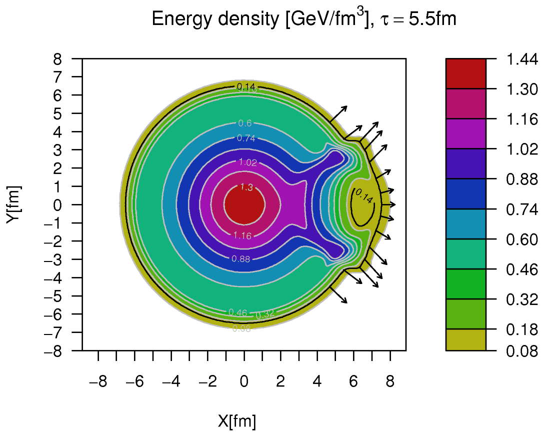

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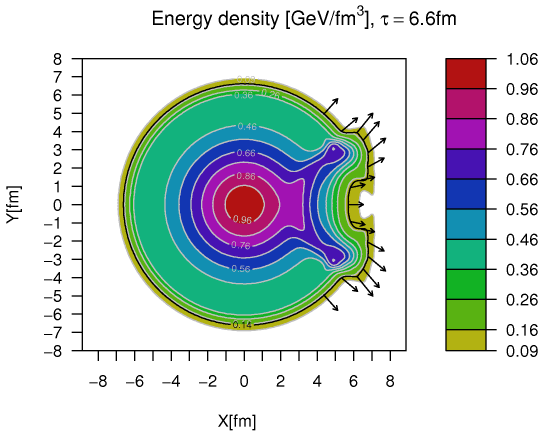

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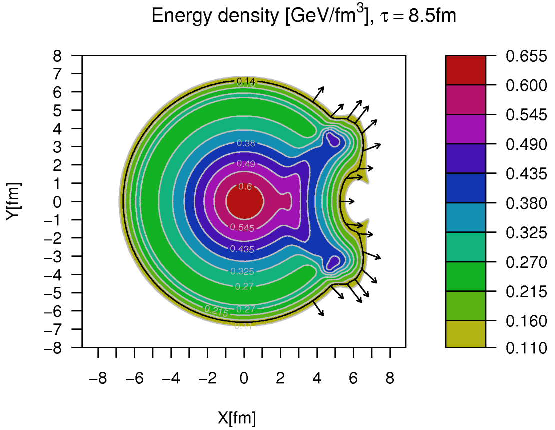

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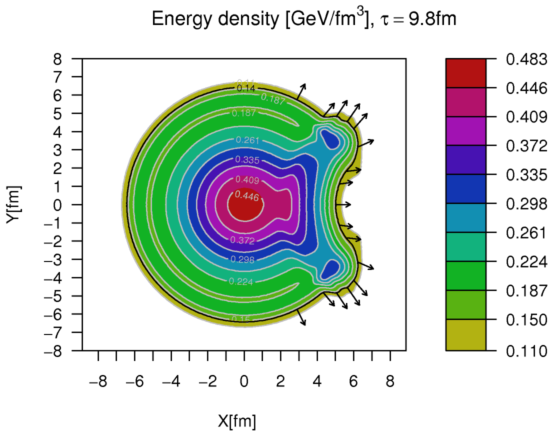

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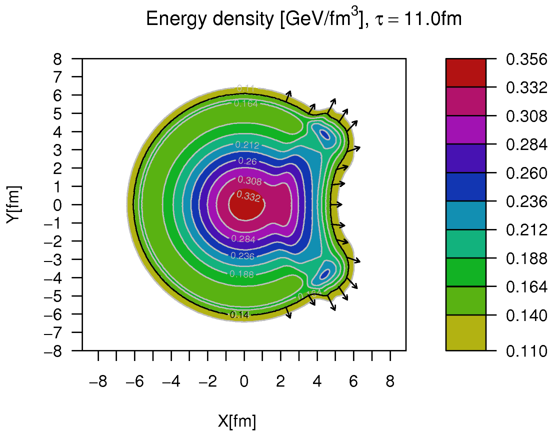

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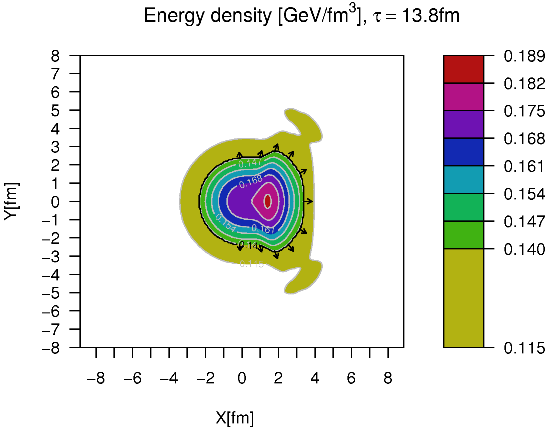
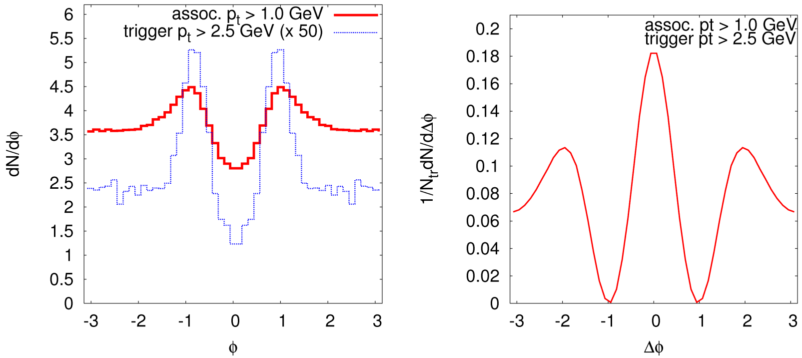


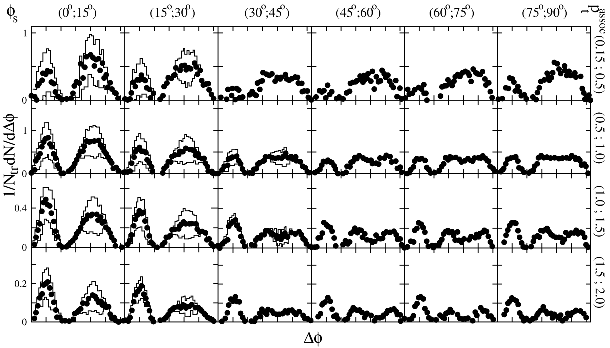
ϕ distributions (left) and two-particle correlation (right) produced by a tube + the average background



Outline

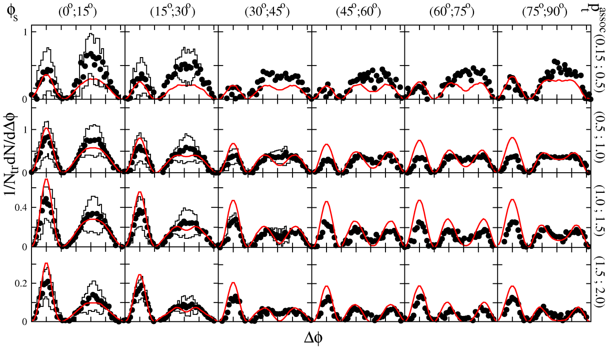
What is in-plane/out-of-plane effect?

In non-central collisions (20-60% centrality), data have been obtained, fixing the azimuthal angle of the trigger (ϕ_S) (STAR Collab., A. Feng et al., J.Phys. G**35** (2008) 104082).



In-plane/out-of-plane effect

Comparison of NeXSPheRIO results (red line) on the in-plane/ out-of-plane effect with STAR data (A. Feng et al., J.Phys. G**35** (2008) 104082) for 20-60% centrality and $3 < p_T^{trigg} < 4$ GeV.



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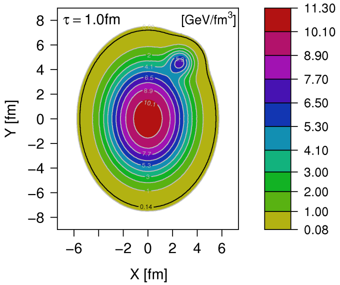
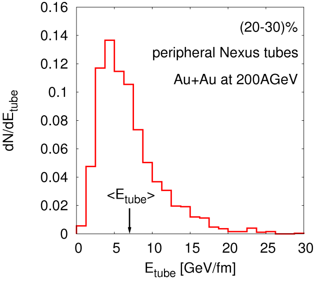
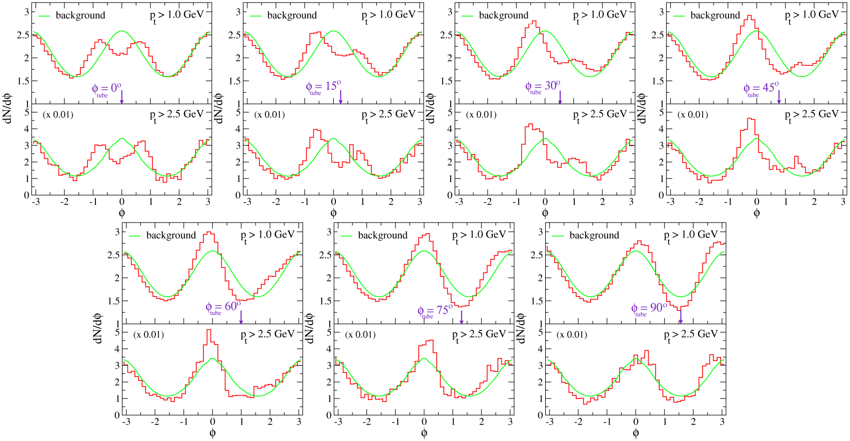
One-tube model for peripheral collisions

We tried to understand this effect by using our one-tube model.

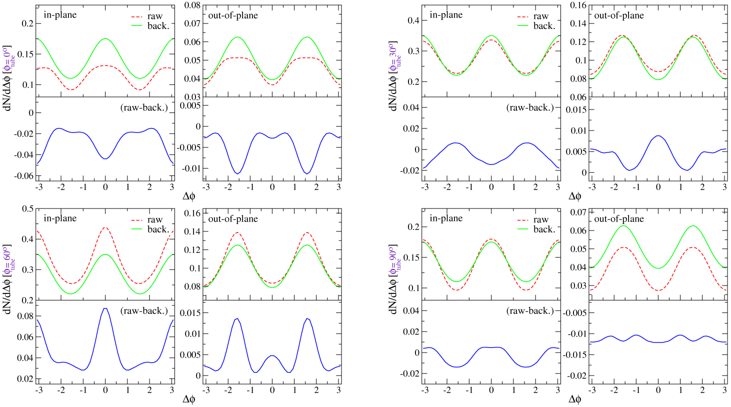




In-plane/out-of-plane effect: one-tube model - $dN/d\phi$

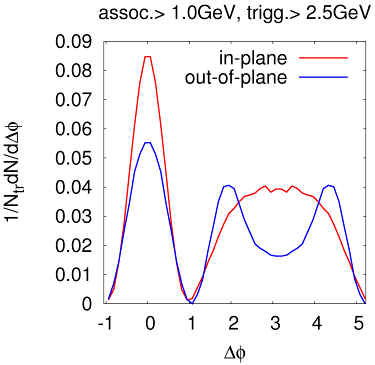


In-plane/out-of-plane effect: one-tube model - correlation



In-plane/out-of-plane effect: one-tube model

Final results for two-particle correlations



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In-plane/out-of-plane effect: one-tube model

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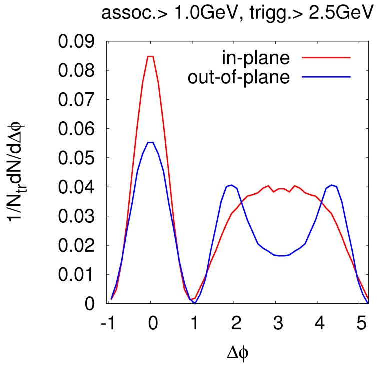

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Simple analytical model

Since the previous results are still not clarifying, we tried the following analytical model, which is valid if the amplitude of fluctuations is small enough:

$$\frac{dN}{d\phi}(\phi, \phi_t) = \frac{dN_{background}}{d\phi}(\phi) + \frac{dN_{tube}}{d\phi}(\phi, \phi_t),$$

where

$$\frac{dN_{background}}{d\phi}(\phi) = \frac{N_b}{2\pi}(1 + 2v_2^b \cos(2\phi)) \quad \text{and}$$

$$\frac{dN_{tube}}{d\phi}(\phi, \phi_t) = \frac{N_t}{2\pi} \sum_{n=2,3} 2v_n^t \cos(n[\phi - \phi_t]) .$$

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Simple analytical model

The two-particle correlation is given by

$$\langle \frac{dN_{pair}}{d\Delta\phi}(\phi_s)\rangle = \langle \frac{dN_{pair}}{d\Delta\phi}(\phi_s)\rangle^{proper} - \langle \frac{dN_{pair}}{d\Delta\phi}(\phi_s)\rangle^{mixed},$$

where, in one-tube model,

$$\langle \frac{dN_{pair}}{d\Delta\phi}\rangle^{proper} = \int \frac{d\phi_t}{2\pi} f(\phi_t) \frac{dN}{d\phi}(\phi_s, \phi_t) \frac{dN}{d\phi}(\phi_s + \Delta\phi, \phi_t) \quad \text{and}$$

$$\langle \frac{dN_{pair}}{d\Delta\phi}\rangle^{mixed} = \int \frac{d\phi_t}{2\pi} f(\phi_t) \int \frac{d\phi'_t}{2\pi} f(\phi'_t) \frac{dN}{d\phi}(\phi_s, \phi_t) \frac{dN}{d\phi}(\phi_s + \Delta\phi, \phi'_t)$$

and ϕ_s is the trigger angle ($\phi_s = 0$ for in-plane and $\phi_s = \frac{\pi}{2}$ for out-of-plane). We will take $f(\phi_t) = 1$, for simplicity.

Simple analytical model

Using our simplified parametrization, the two-particle correlation for the in-plane trigger case is given as

$$\langle\frac{dN_{pair}}{d\Delta\phi}\rangle_{in}^{proper} = \frac{< N_b^2 >}{(2\pi)^2}(1+2v_2^b)(1+2v_2^b\cos(2\Delta\phi)) + (\frac{N_t}{2\pi})^2\sum_{n=2,3}2(v_n^t)^2\cos(n\Delta\phi) \quad \text{and}$$

$$\langle\frac{dN_{pair}}{d\Delta\phi}\rangle_{in}^{mixed} = \frac{< N_b >^2}{(2\pi)^2}(1+2v_2^b)(1+2v_2^b\cos(2\Delta\phi)) .$$

Simple analytical model

So, by subtracting each other, the in-plane correlation is

$$\langle \frac{dN_{pair}}{d\Delta\phi} \rangle_{in} = \frac{< N_b^2 > - < N_b >^2}{(2\pi)^2}(1 + 2v_2^b)(1 + 2v_2^b \cos(2\Delta\phi)) + (\frac{N_t}{2\pi})^2 \sum_{n=2,3} 2(v_n^t)^2 \cos(n\Delta\phi) .$$

Similarly, the out-of-plane correlation is given as

$$\langle \frac{dN_{pair}}{d\Delta\phi} \rangle_{out} = \frac{< N_b^2 > - < N_b >^2}{(2\pi)^2}(1 - 2v_2^b)(1 - 2v_2^b \cos(2\Delta\phi)) + (\frac{N_t}{2\pi})^2 \sum_{n=2,3} 2(v_n^t)^2 \cos(n\Delta\phi) .$$

The contribution of the backgound v_2 has opposite signs in these cases ! $\Rightarrow$ In-plane/out-of-plane effect

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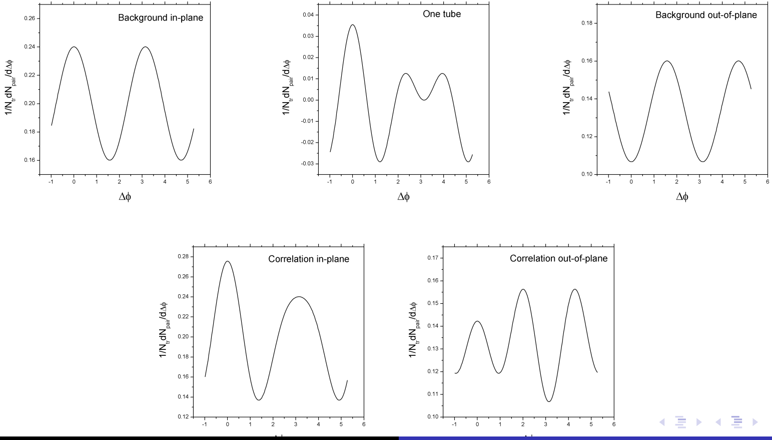
The multiplicity fluctuation is essential.

Simple analytical model

With an appropriate choice of parameters, we have



Summary

- Hydrodynamic expansion starting from fluctuating IC with tubular structure produces ridge structure in the 2-particle correlation.
- A high-density peripheral tube 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.

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  - The latter is back-to-back ($\Delta\phi = 0 - \pi$) in the case of in-plane triggers ($\phi_S \sim 0$) and
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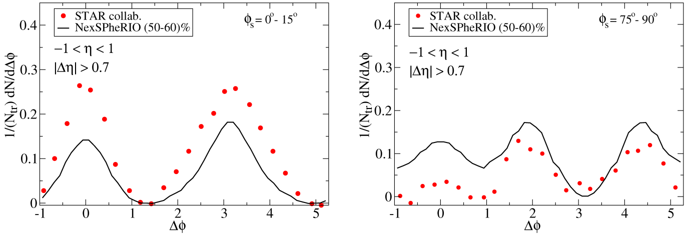
- In non-central collisions, the NeXSPheRIO code gives correct qualitative behavior of the in-plane/out-of-plane effect.
- A simplified analytical one-tube model shows that this effect appears because, besides the contribution coming from the peripheral tube, additional contribution arises from the background elliptical flow, due to the multiplicity fluctuation.
  - The latter is back-to-back ($\Delta\phi = 0 - \pi$) in the case of in-plane triggers ($\phi_S \sim 0$) and
  - rotated by $\pi/2$ ($\Delta\phi = -\pi/2 - -\pi/2$)in the case of out-of-plane triggers ($\phi_S \sim \pi/2$).

Summary

See more in Mota's and Gardim's talks.

In-plane/out-of-plane effect: new data

New data have been obtained, excluding jets, by taking particles with $|\Delta\eta| > 0.7$ (STAR Collab., H. Agakishiev et al., arXiv:1010.0690[nucl-ex]).



Our preliminary results, by using NEXSPheRIO, are shown for comparison.