Hydrodynamics: Fluctuating Initial Conditions and Two Particle Correlations

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Saturation-CGC-Glasma Workshop

Outline

3+1 hydrodynamics: comparison with data (W.-L. Qian)

$\longrightarrow$ gives access to long range pseudo-rapidity correlations

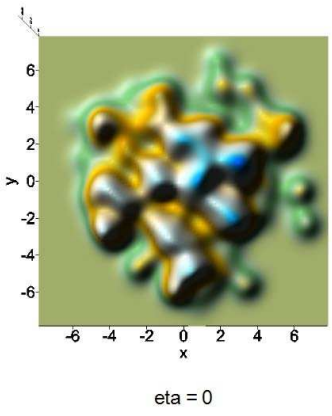
- Traditional approach: smooth initial conditions
  T.Hirano et al.,
  C.Nonaka/S.Bass et al.,
  etc.
- Fluctuating initial conditions approach: mimic experience by starting from different irregular initial conditions and running many times
  SPheRIO group (Brazil),
  H.Petersen/M.Bleicher et al. (Frankfurt/Duke),
  K.Werner et al. (Nantes-Kiev-Karlsruhe-Frankfurt -Moscow).

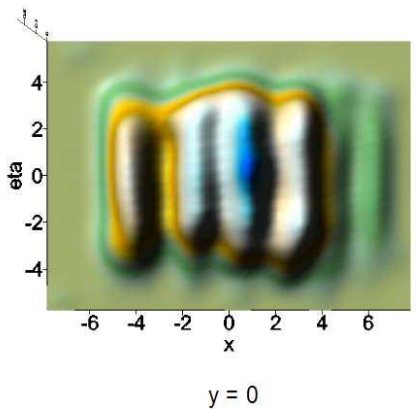
Hydrodynamics with fluctuating initial conditions: differences between models and references on two particle correlations

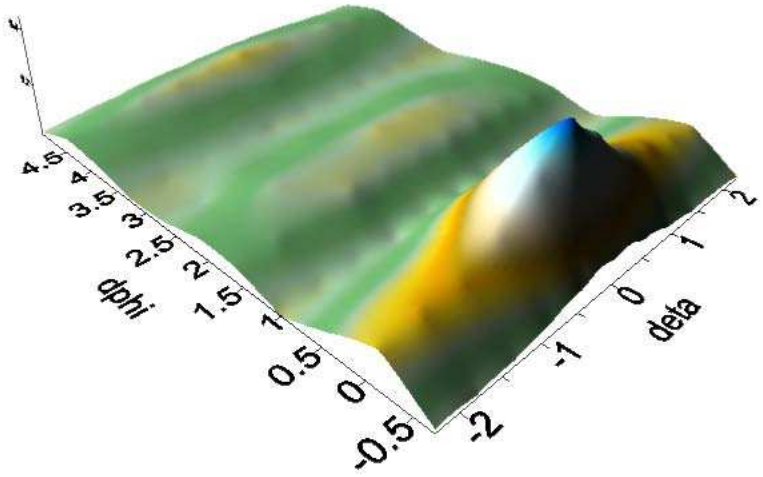
- SPheRIO group: NeXus initial conditions+ ideal (SPH) hydro
  Phys. Rev. Lett. 103, 242301 (2009), arXiv:0911.0811 and 0912.0703
- H.Petersen/M.Bleicher et al.: UrQMD initial conditions+ ideal (grid) hydro
  only midrapidity variables at RHIC (private communication)
- EPOS initial conditions+ ideal (grid) hydro
  K.Werner et al. ArXiv:1004.0805

NeXSPheRIO: dihadron $\Delta\eta - \Delta\phi$ correlations

- Initial conditions have tubular structures,
- two particle correlations exhibit *near* and *away-side* ridges,
- double check: use of two different methods for v_2 subtraction (ZYAM+ event plane alignment).



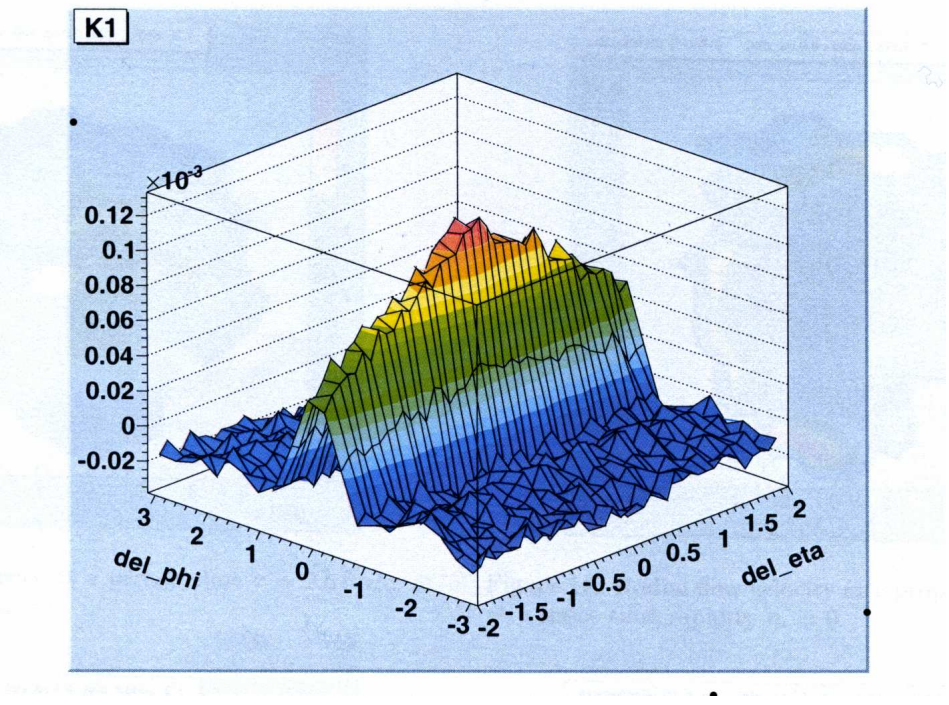




NeXSPheRIO central collisions Au+Au at 200 GeV A (2.5 GeV $\times$ 1.5 GeV).

K.Werner et al: dihadron $\Delta\eta - \Delta\phi$ correlations

- Initial conditions also have tubular structures,
- two particle correlations exhibit near-side and *small* away-side ridges (K.Werner/private communication).



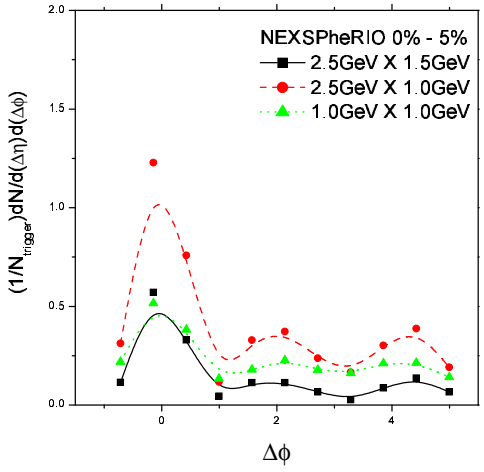
EPOS central collisions: Au+Au at 200 GeV A (3 GeV $\times$ 2 GeV).

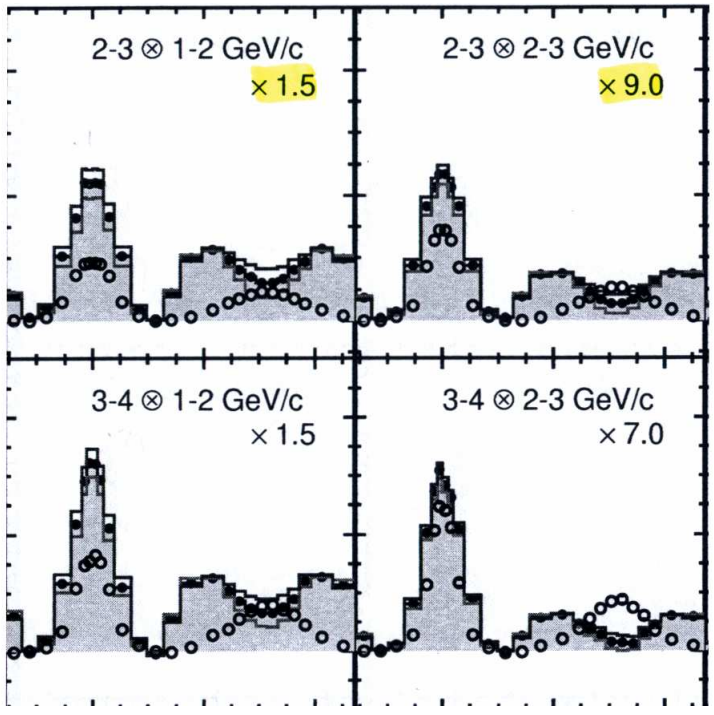
NeXSPheRIO: good qualitative agreement with various data:

p_t behavior

▷ Fixed p_t^{trigg}, p_t^{assoc} ↗: near-side and away-side peaks ↘

▷ Fixed p_t^{assoc}, p_t^{trigg} ↗: peaks ↗.

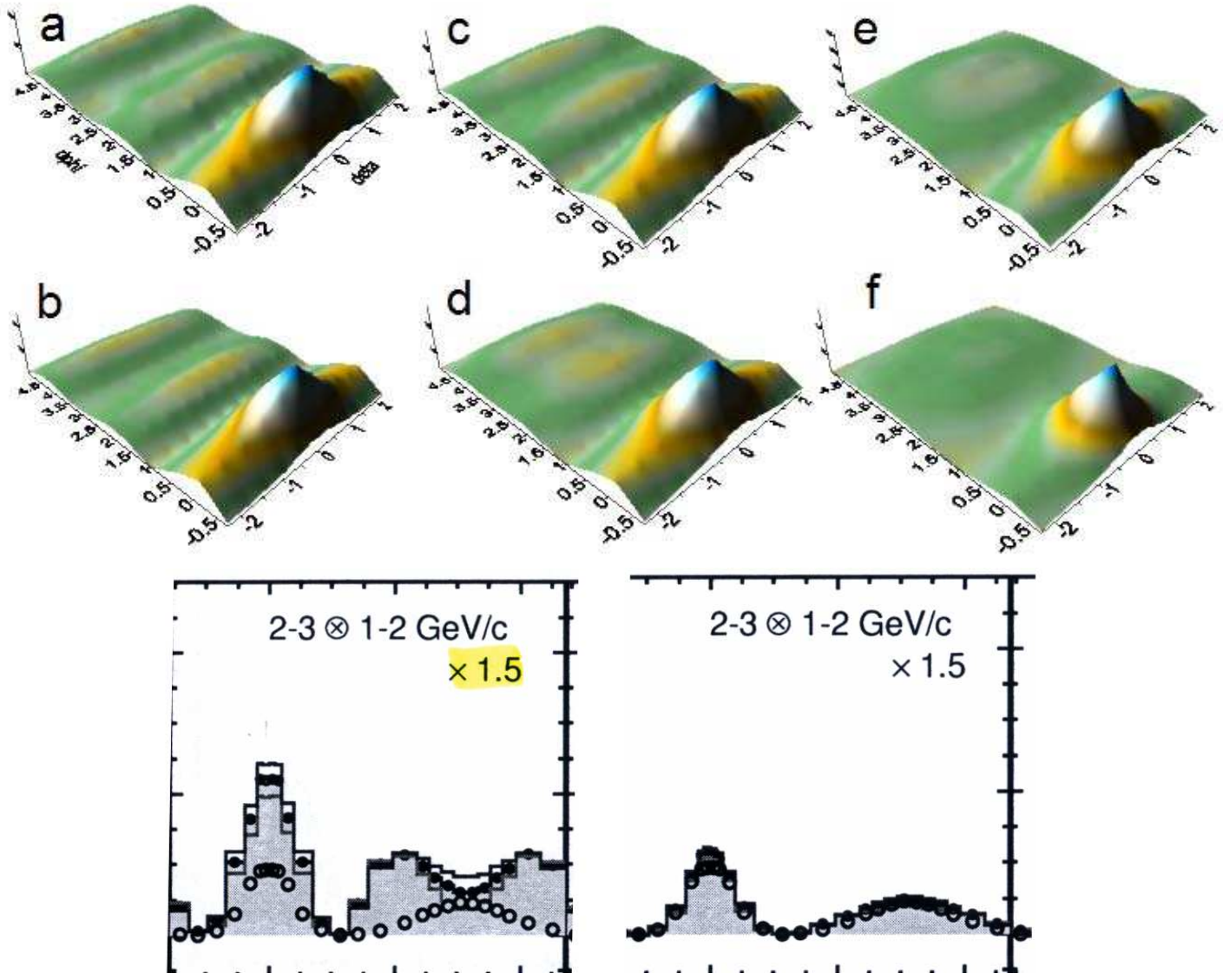




NeXSPheRIO results for central Au+Au and PHENIX results (black dots) for 0-20% Au+Au collisions (PRC78(2008) 014901, PRC77 (2008) 011901R).

Centrality dependence

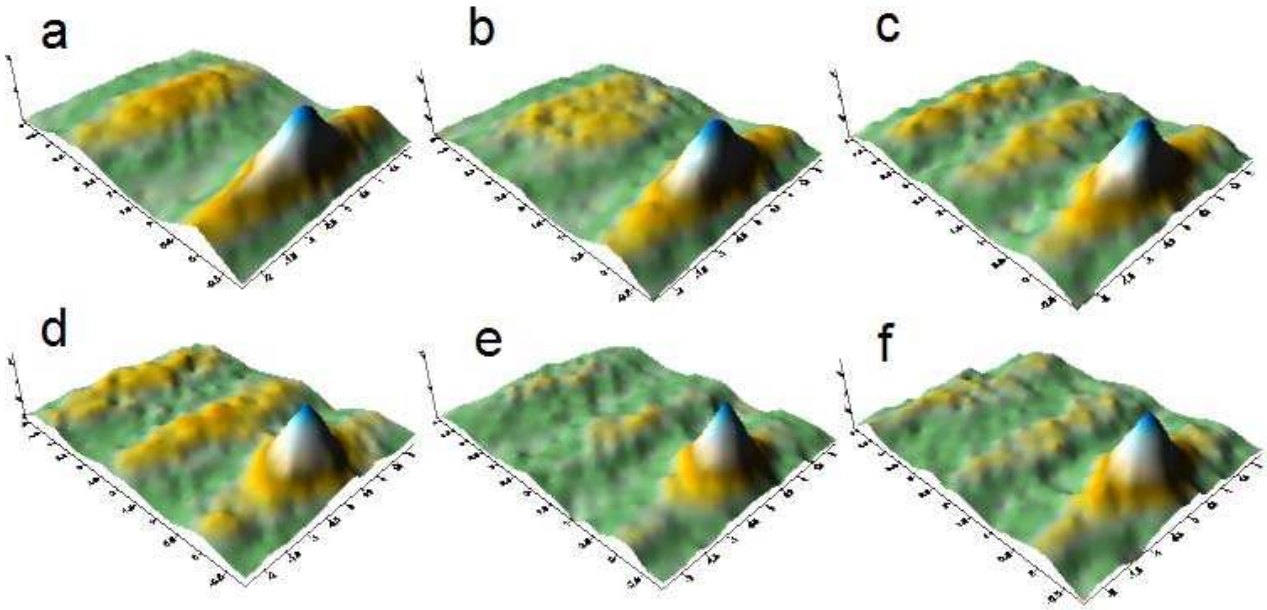
▷ Away-side: double to single peak

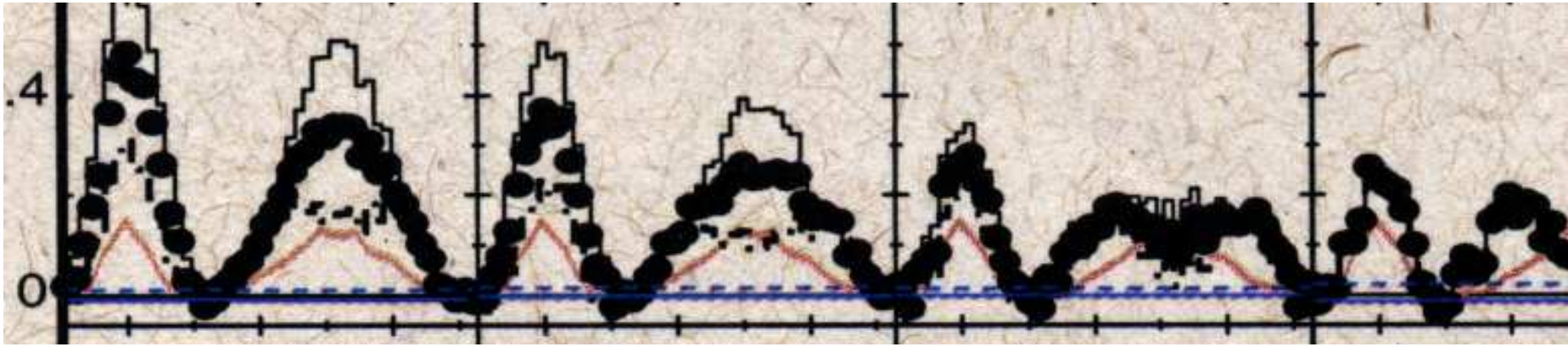


NeXSPheRIO and PHENIX results for central to peripheral collisions

In-plane/out-of-plane trigger

- ▷ central collisions: double away-side peak
- ▷ less central: single to double away-side peak





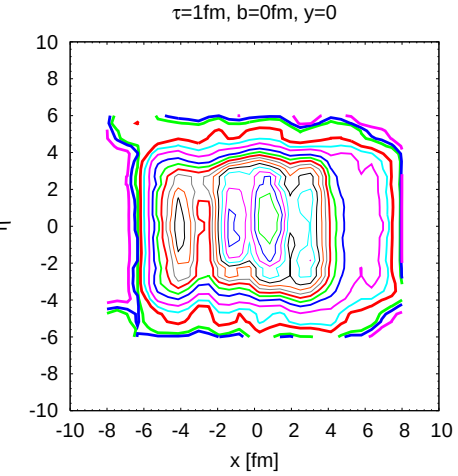
NeXSPheRIO (20-30%) and STAR (20-60%) results for in-plane to out-of-plane trigger (JPG 35 (2008) 104082.

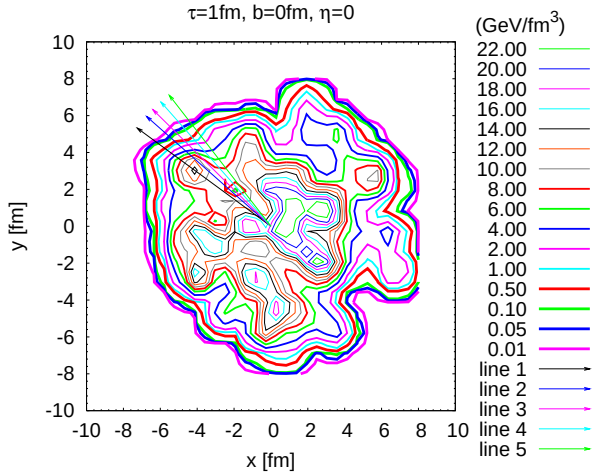
2+1 hydrodynamics: one tube model (R.Andrade Ph.D. Thesis)

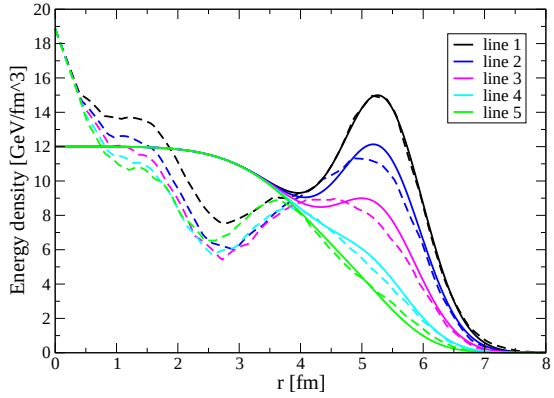
WHY 3+1 HYDRO GIVES GOOD RESULTS?

$\longrightarrow$ Study transverse expansion of a slice with one tube

- longitudinal boost invariance assumed
- central collision
- profile inspired by NeXus initial conditions



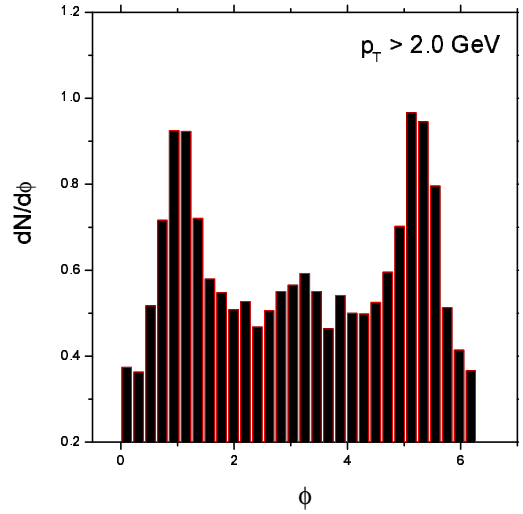




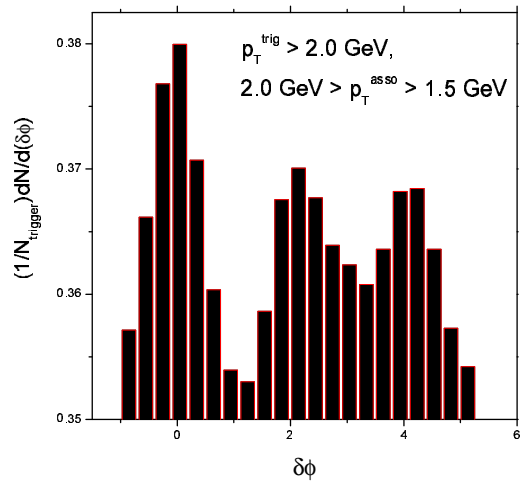
Choice of a realistic slice.

One tube model

MAIN RESULT: single particle angular distribution has TWO PEAKS separated by $\Delta phi \sim 2$

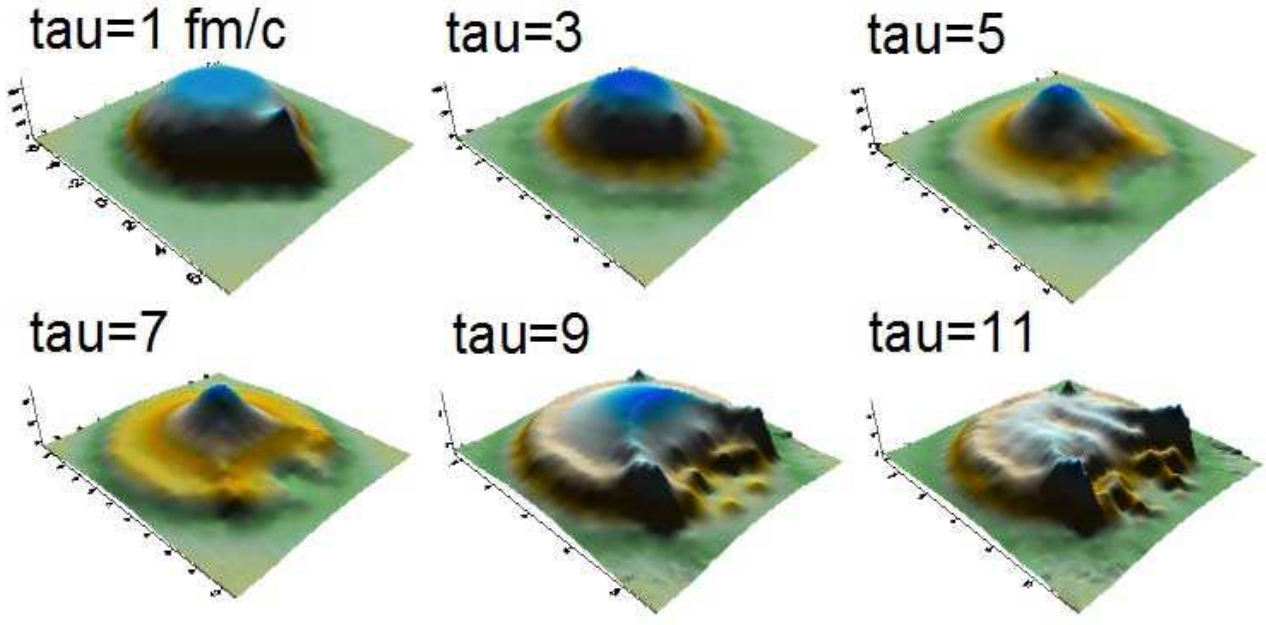


CONSEQUENCE: two particle angular distribution has three peaks



Origin of the two peaks

Tube “sinks” and matter around “rises” forming a hole+two horns

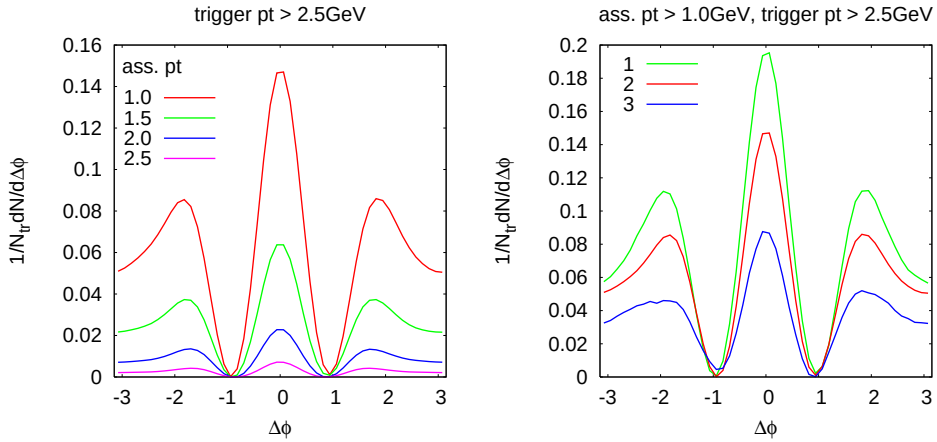


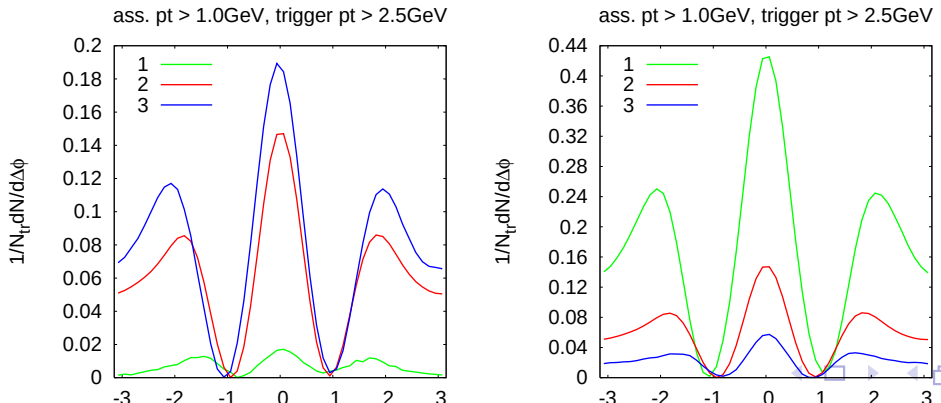
Temporal evolution of energy density for the one tube model.

Dependence on tube parameters

Two particle angular distribution:

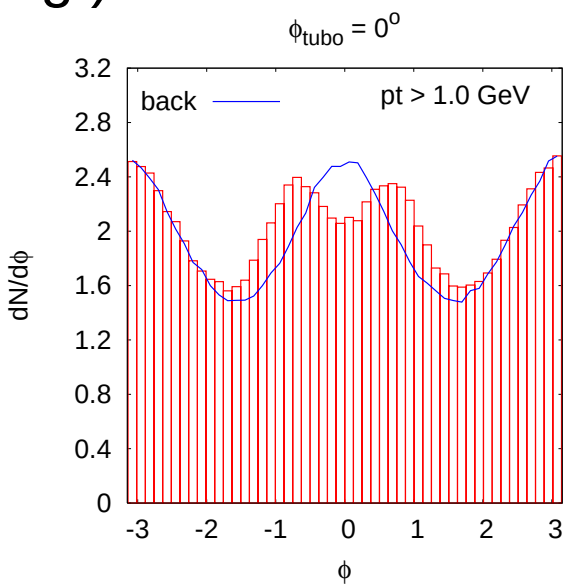
- almost insensitive to background height and initial tranverse velocity
- sensitive (in intensity, not shape) to
  - ▷ p_t value
  - ▷ tube height, radius, position
- attenuated by long-tailed background (not seen in NeXus)

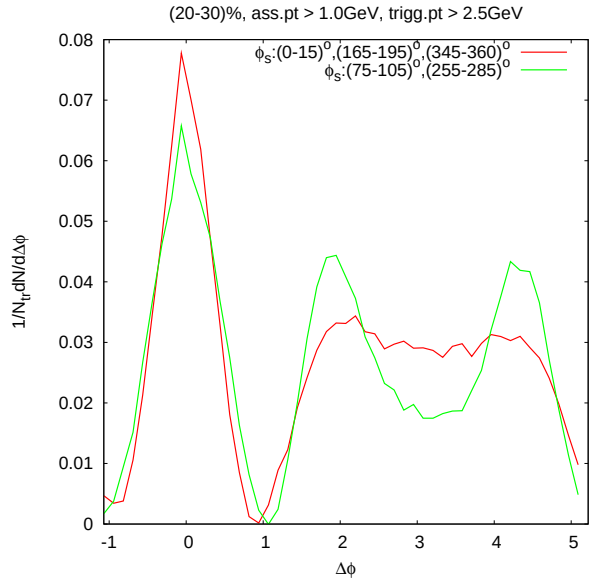




Dependence on centrality

- single particle angular distribution may have TWO PEAKS with separation $\Delta\phi \sim 2$ also for 20-30 % Au+Au (left fig.)
- two particle angular distribution: in-plane/out-of-plane trigger correlation may have a single/double peak (right fig.)



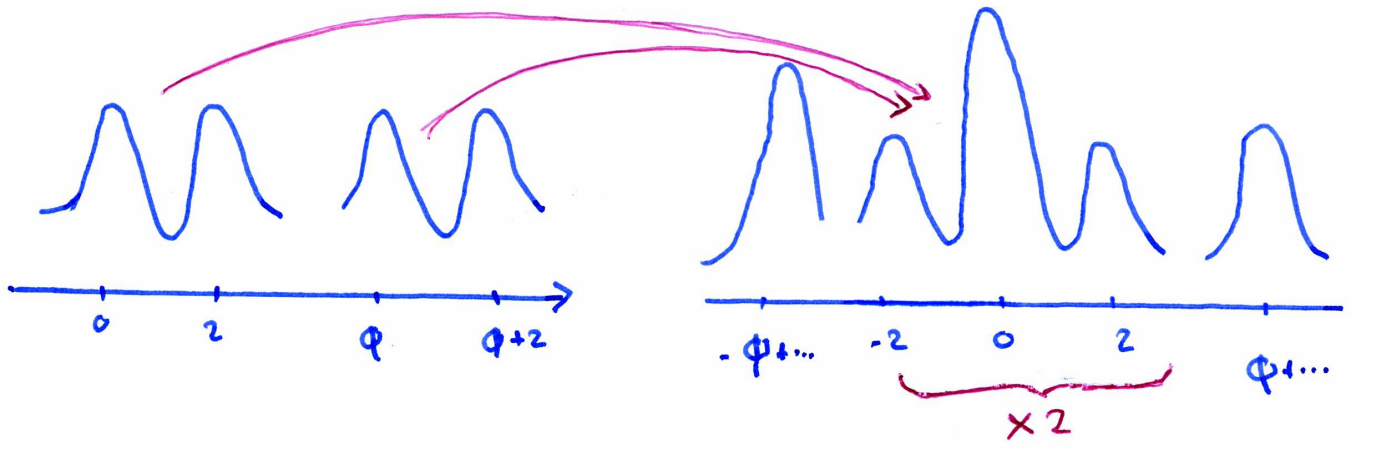


left: large v_2 but tube is still visible; right: one tube model prediction (also true for NeXus slice).

Several tubes

Correlation shape $\sim$ independent of radius, height, position

$\Rightarrow$ for n tubes in 1 event, the basic structure small-large-small peaks is reinforced.



Possible tests

Expectation: one tube $\Rightarrow$ one peak in particle azimuthal distribution

- S.A.Voloshin PLB632 (2006) 490
- A.Dumitru et al. NPA810 (2008) 91
- S.Gavin et al. PRC79 (2009) 051902
- and others

Other expectation: tubes may become holes (no emission)

- E.Shuryak PRC80 (2009) 054908
- Yu.Sinyukov (private communication/simulation)

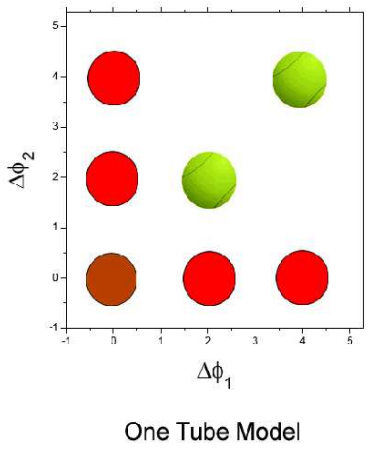
One tube model: one tube $\Rightarrow$ two peaks

HOW TO TEST THIS?

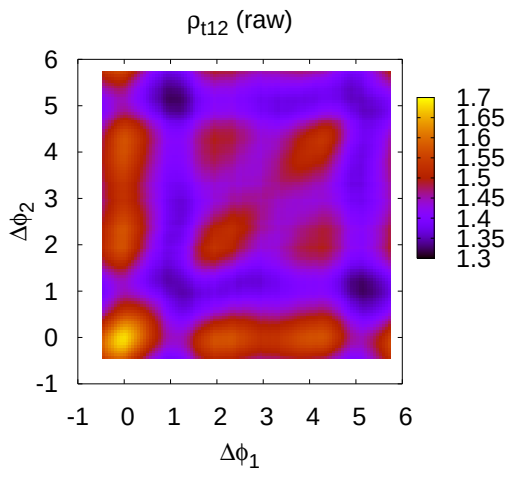
Three particle correlations in $\Delta\phi_1 = \phi_1 - \phi_t$ and $\Delta\phi_2 = \phi_2 - \phi_t$ (in progress)

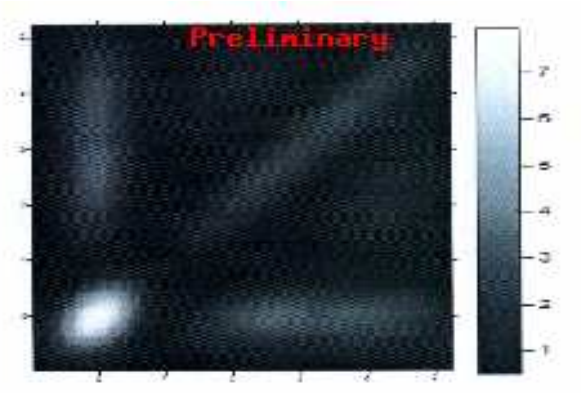
Data by STAR (PRL 102(2009) 052302) and PHENIX (NPA783 (2007) 519).

- Theory: one tube prediction is clean "no off diagonal peaks" (left fig.)
- Practice: "off diagonal peaks" present
  - ▷ one tube RAW result (center fig.) (peaks not sharp)
  - ▷ in NeXSPheRIO result w/subtraction (right fig.)



One Tube Model





Other models: Mach cone (Renk & Ruppert PRC76 (2007) 014908), AMPT (G.L.Ma et al. PLB647 (2006) 122), etc, have similar "off diagonal" predictions.

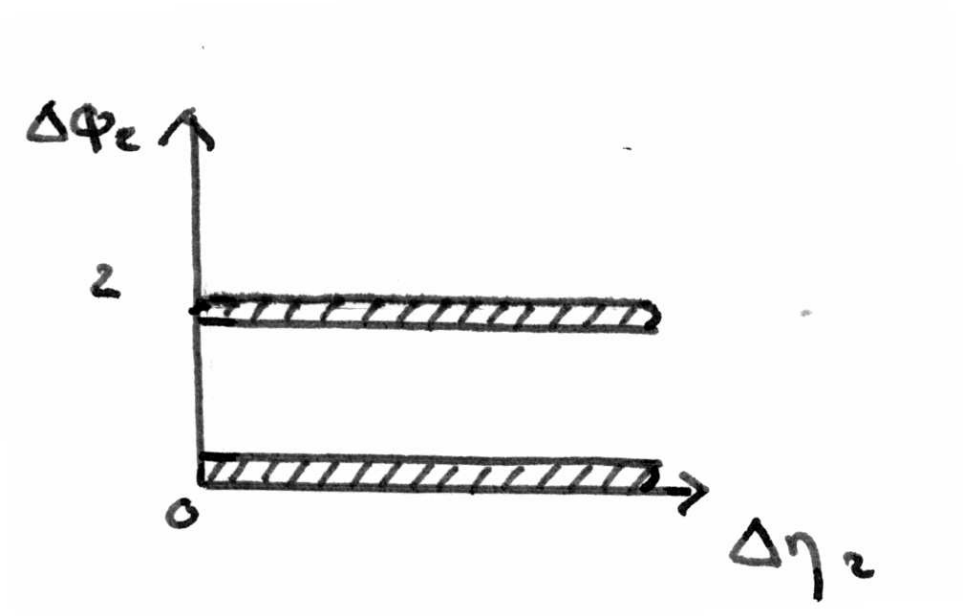
2+1 correlations in $\Delta\phi_2$-$\Delta\eta_2$ with the restriction: $\Delta\phi_1 \sim 2$ (in progress)

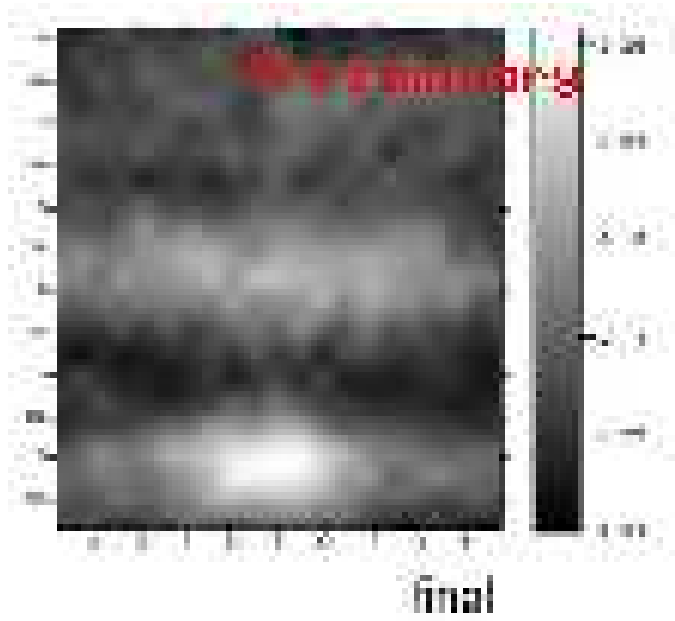
One tube prediction:

trigger and first associated particle preferably in separate peaks

$\Rightarrow$ second associated particle preferably in one of the TWO peaks

$\Rightarrow$ two stripes separated by $\Delta\phi \sim 2$.





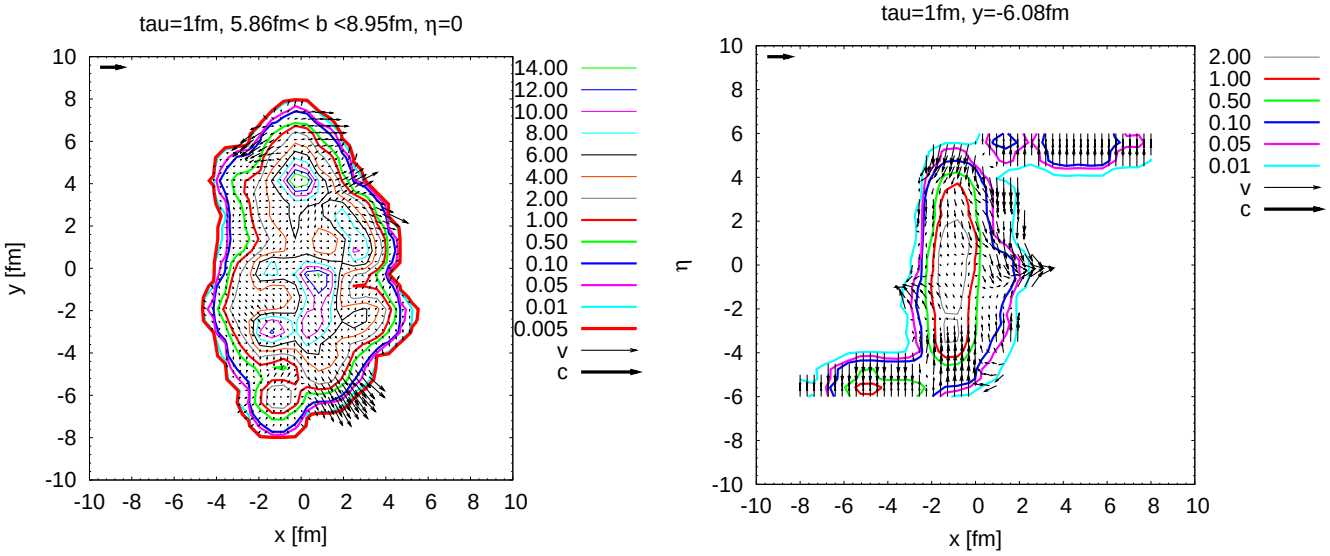
left: prediction; right: NeXSPheRIO result w/subtraction (30-40% 1.5 GeV $\times$ 1.5GeV). (Central collisions should be better sited.)

Summary

- Hydrodynamics with tubular initial conditions predicts two-particle correlations in qualitative agreement with data.
- Near-side and away-side structures are related to “two horn” emission from each tube.
- Possible test: 2+1 correlation in $\Delta\phi_2$-$\Delta\eta_2$ with the restriction $\Delta\phi_1 \sim 2$.

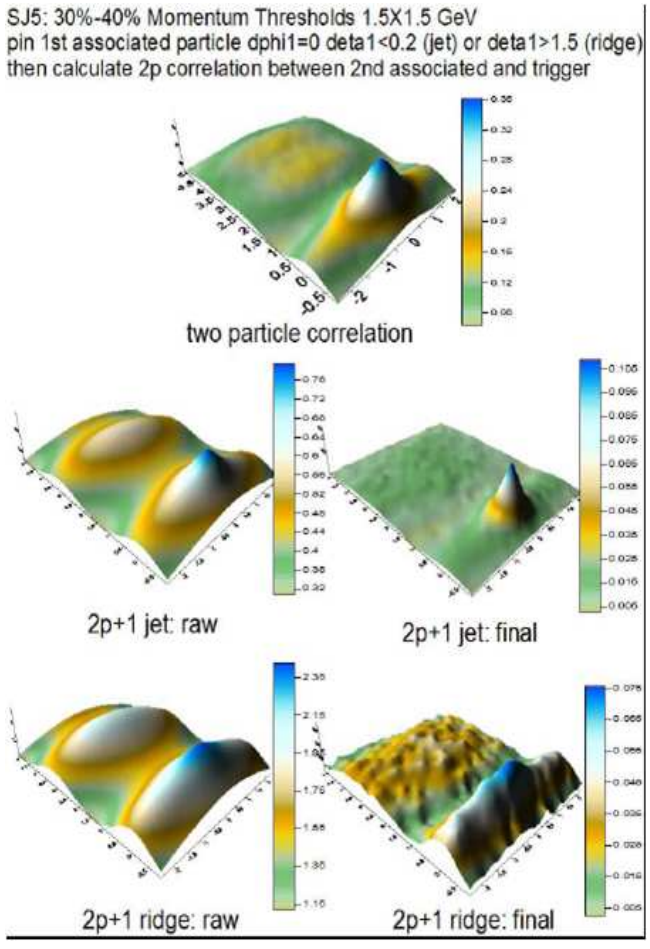
Back up slides

The peak on the near-side ridge

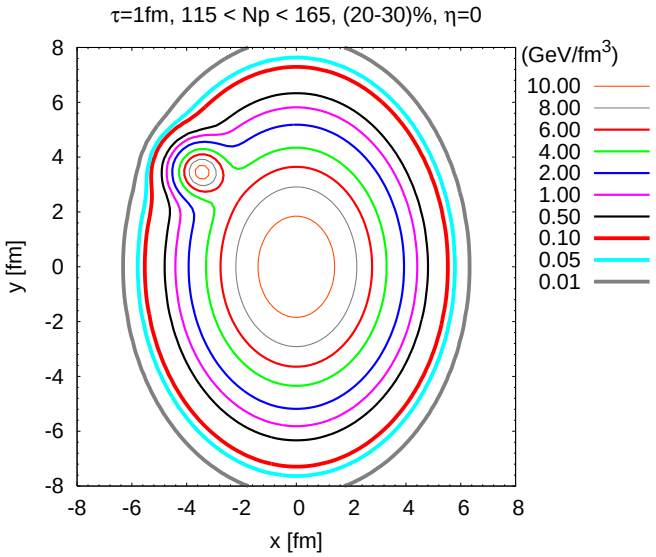


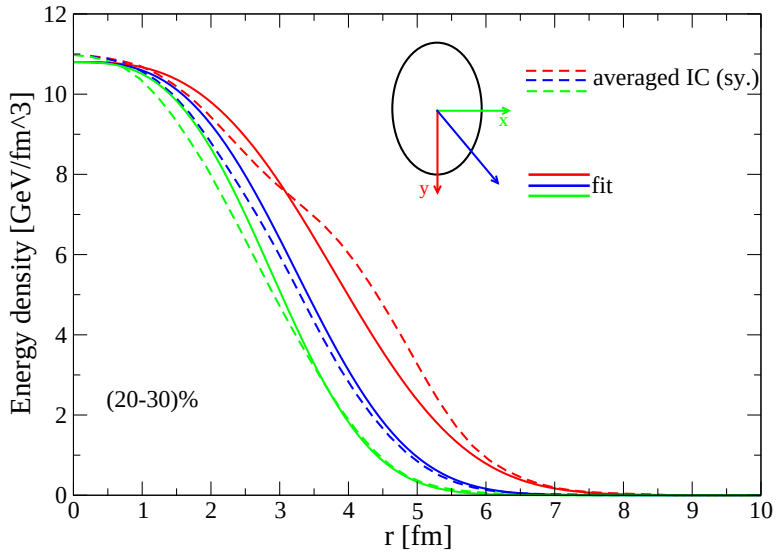
NeXSPheRIO initial fluid velocity for a Au+Au collisions at 200 GeV A in the 25-35% centrality window.

Independence peak-near-side ridge (preliminary)

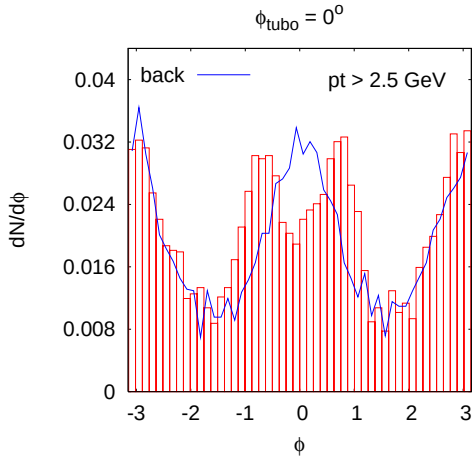


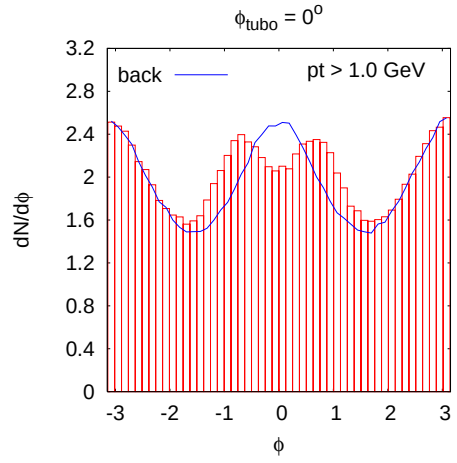
One tube mdel: non central collisions

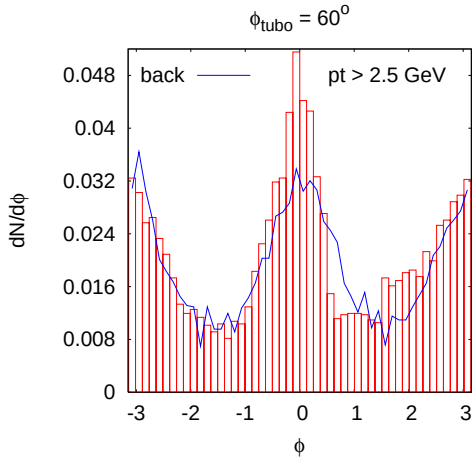


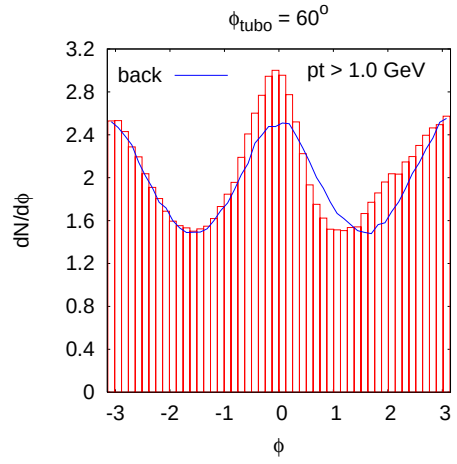


One tube model: non central collisions/cont.

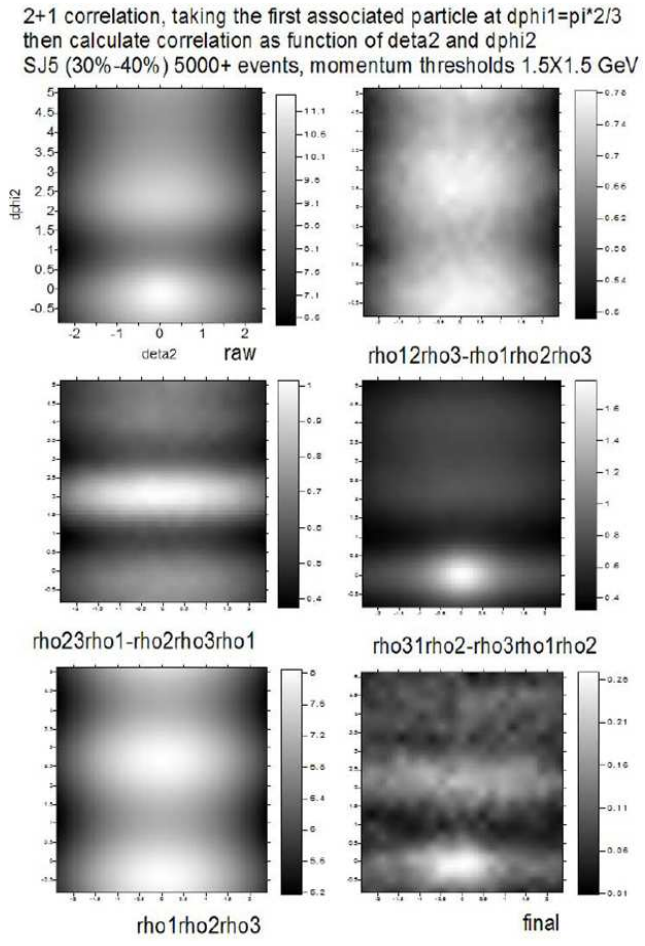






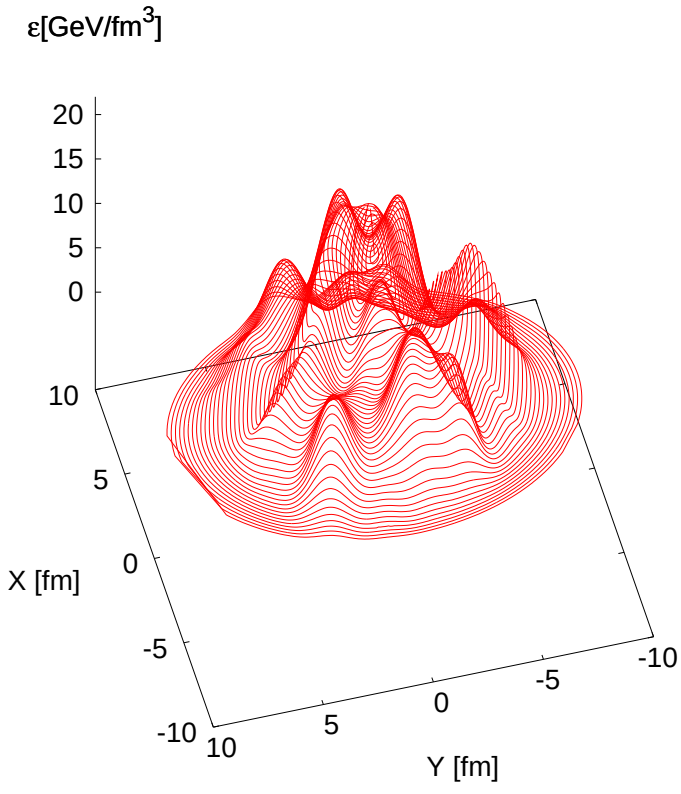


Subtraction for 2+1 correlations (preliminary)

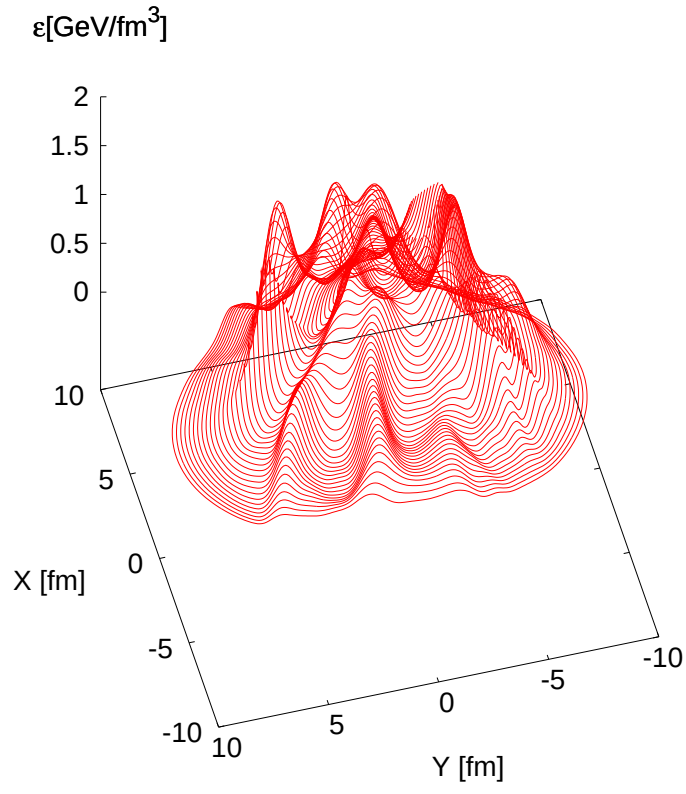


Tubes and holes in NeXSPheRIO

Nexus, Au+Au, central, τ = 1.0fm



Nexus, Au+Au, central, τ = 4.4fm



Tubes and fingers in EPOS+hydrodynamics

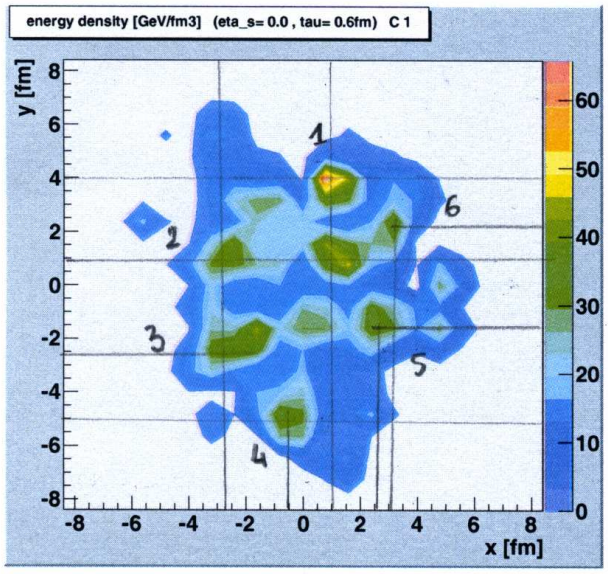


Figure **14**: Initial energy density in a central Au-Au collision at 200 GeV, at a space-time rapidity $\eta_s = 0$.

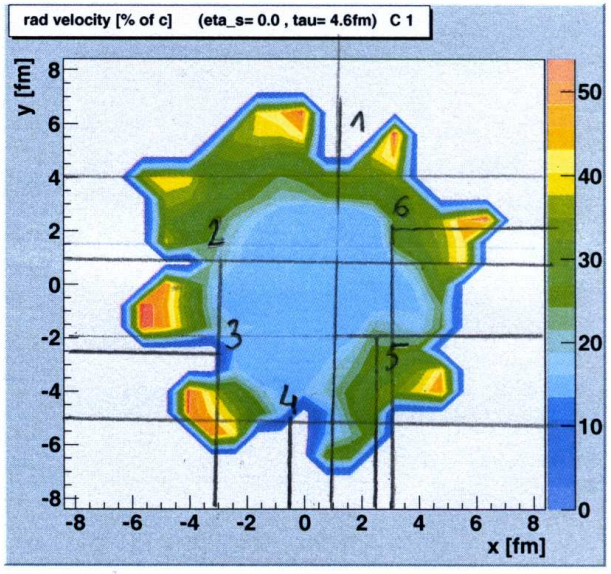


Figure **22**: Radial flow velocity at a proper time $\tau = 4.6\,\mathrm{fm/c}$, at a space-time rapidity $\eta_s = 0$.