# Event-by-event hydrodynamical evolution

R.P.G.Andrade[1], A.L.V.R.dos Reis[1], F.Grassi[1], Y.Hama[1], T.Kodama[2], W.L.Qian[1]

[1]Instituto de Física, Universidade de São Paulo, Brazil

[2]Instituto de Física, Universidade Federal do Rio de Janeiro, Brazil

C.Aguiar, T.Osada, O.Socolowski Jr.
K.Werner and collaborators
J.-Y.Ollitrault
J.Takashi, B.Tavares, N.Xu
G.Denicol, F.Mota

# Outline

- Objective
- SPheRIO code
- Fluid evolution
- Comparison between hydro with smooth I.C. and EbE hydro
- Summary

# Objective

*Hydrodynamics has been rather successful at describing results obtained in relativistic nuclear collisions at RHIC.*

Usually, smooth initial conditions are assumed.

For example:

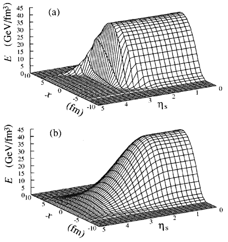



FIG. 1. Initial energy density in the reaction plane ($y=0$ and $\eta_s>0$) in Au + Au collisions at 130$A$ GeV. (a) The initial condition $A$. (b) The initial condition $B$. The impact parameter $b$ is 2.4 fm. See text for details.

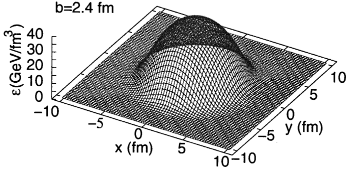
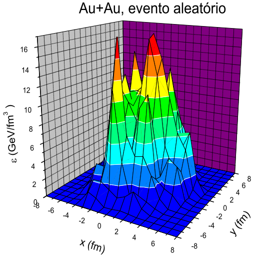
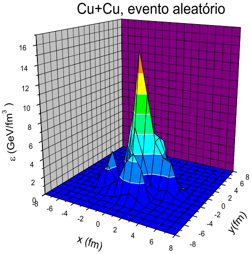



FIG. 3: Initial energy density on the transverse plane at Au+Au $\sqrt{s_{NN}}$ = 200 GeV central collisions (b=2.4 fm) in the case of Hydro + UrQMD.

left: T.Hirano Phys.Rev.C65 (2001) 011901R; right: C.Nonaka and S.Bass Phys.Rev.C75 (2007) 014902.

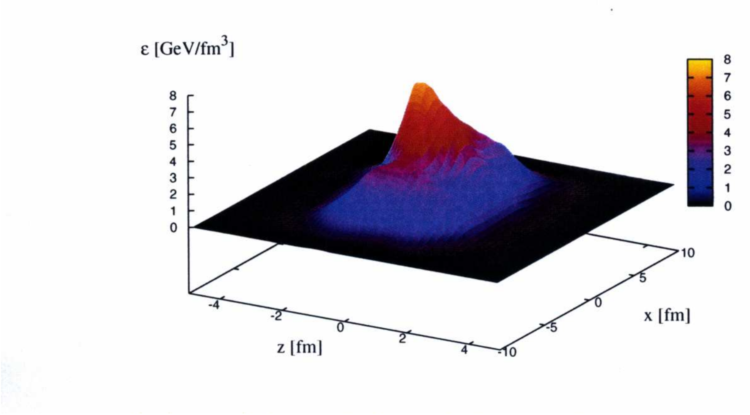
In reality, one expects that initial conditions event-by-event, are not smooth.
Here are examples from NeXuS:




Initial energy density of a RHIC collision in the 6-15% centrality window, in the transverse plane.

## Here is an example from UrQMD:




Initial energy density of a Pb+Pb central collision at $E_{lab} = 40A\,GeV$, in the reaction plane.

H.Petersen at al. arXiv:0806.1695

Can such structures have a sizable effect on variables?

# SPheRIO code

To solve the hydro equations with very irregular initial conditions, we use the SPheRIO code:

It is based on the method of **Smoothed Particle Hydrodynamics**, originally developed in astrophysics and adapted to relativistic heavy ion collisions

C.E.Aguiar, T.Kodama, T.Osada & Y.Hama, J.Phys.G27(2001)75;

Y.Hama, T.Kodama & O.Socolowski Jr. Braz.J.Phys. 35(2005)24

## SOME DETAILS

- initial conditions provided by NeXus
  H.J. Drescher, F.M. Liu, S. Ostrapchenko, T. Pierog and K. Werner, Phys. Rev. C65 (2002) 054902
  and normalized by an $\eta$-dependent factor to reproduce $dN_{ch}/d\eta$ in each centrality window
  Y.Hama et al. *et al.* Yad. Fiz. **71** 1588 (2008)
- eos with a critical point
  Y. Hama *et al.* QM05 proceedings, Nucl.Phys. A**774** 169 (2006)
- $T_{f.out}$ is fixed (mostly) by $dN_{ch}/p_t dp_t$ and depends on the centrality window (i.e. number of participants).
- centrality windows are defined *as experimentally*, using participant number and not impact paremeter
  R.Andrade *et al.* Braz.J.Phys. **34** 319 (2004)
- ideal fluid.

## RELATED PRESENTATIONS

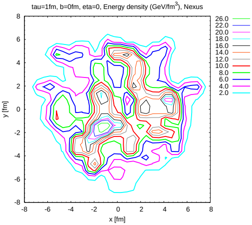
- eos with strangeness $\longrightarrow$ Wei-Liang Qian
- continuous emission $\longrightarrow$ Rone Andrade
- directed flow $\longrightarrow$ Arthur dos Reis
- ridge $\longrightarrow$ Jun Takashi
- SPH with dissipation $\longrightarrow$ Gabriel Denicol and Philipe Mota

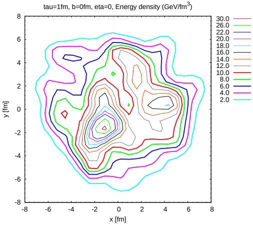
# Fluid evolution

INITIAL CONDITIONS

DIRECTLY FROM NEXUS vs. USED AS INPUT

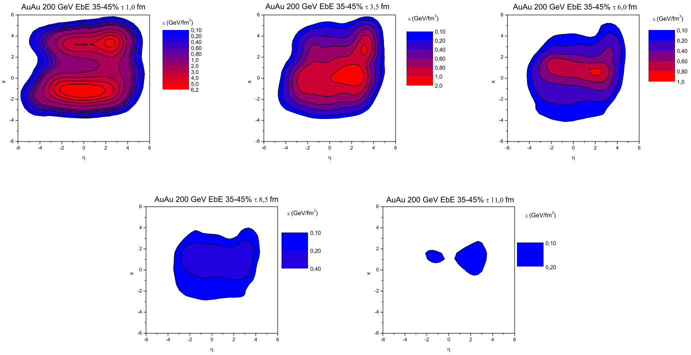
Central collision in the transverse plane



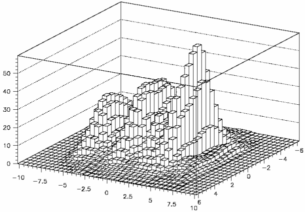

Initial conditions are somewhat smoothed by SPheRIO

# TIME EVOLUTION
## Semi-central collision in the reaction plane




Tube structure formed and maintained

# Initial conditions of EPOS also have a tube structure



# FLUID VELOCITY

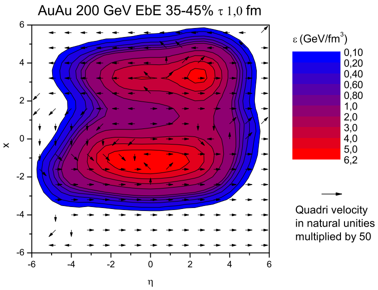
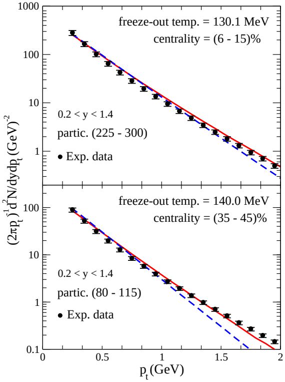



Figure: vectors $(u^x/u^\tau, \tau\, u^\eta/u^\tau)$
Preliminary: fluid expands with rapidity around $th^{-1}z/t$.

# Comparison between hydro with smooth I.C. and EbE hydro

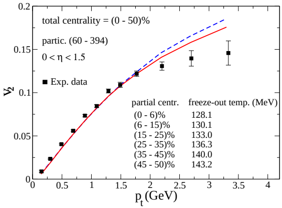
- $p_T$ spectra: the high $p_t$ part is lifted




R.P.G. Andrade et al., Phys. Rev. Lett. 101(2008)112301

Hot tubes expand more violently, producing more high $p_t$ particles.

- $v_2(p_t)$ is flatter

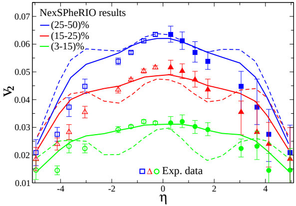



R.P.G. Andrade et al., Phys. Rev. Lett. 101(2008)112301 and Phys. Rev. Lett. 97 (2006) 20230

Isotropic expansion of hot tubes produces more high $p_t$ particles and lowers $v_2(p_t)$

- $v_2(\eta)$ has no shoulder

  ref.: see above




Ref: as previous graph

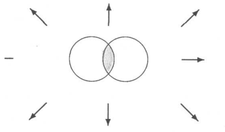
Effects of hot spots very visible in regions of lower matter density

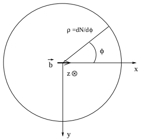
- directed flow

## What is directed flow?

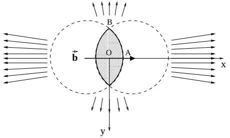
If a nucleus-nucleus collision

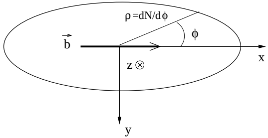
- is a number of *independent nucleon-nucleon collisions* $\Rightarrow$ the momentum distribution is isotropic





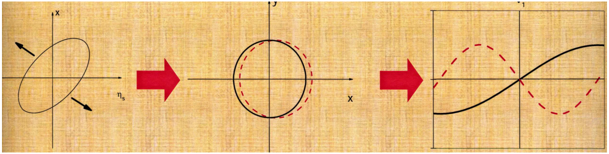

- leads to *thermalized matter* (in overlap region) $\Rightarrow$ the momentum distribution is stretched




$v_2$ = measure of this stretching, so teaches about IC, thermalization, etc

- There is also the possibility that the momentum distribution be shifted/deformed towards one of the sides:

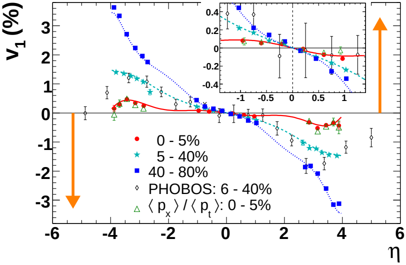



$v_1$ = measure of the shift

# Results on directed flow at RHIC

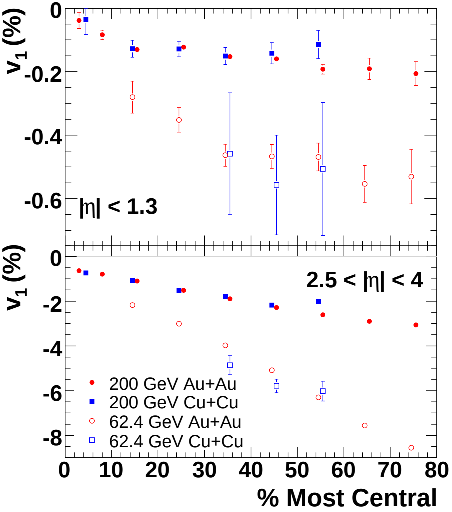
General shape from PHOBOS and STAR

Results are for charged particles (pions dominate) and rather similar to pions from NA49




PHOBOS Phys.Rev.Lett.97 (2006) 012301 and STAR Phys.Rev.Lett.92 (2004) 062301; arXiv:0807.1518

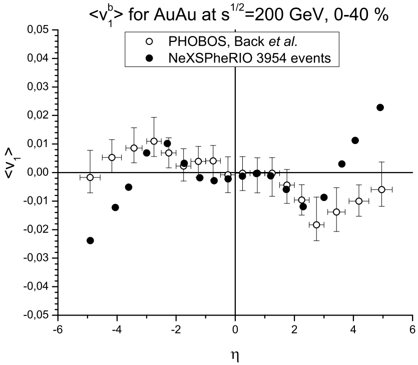
# System-size independence from STAR (arXiv:0807.1518)



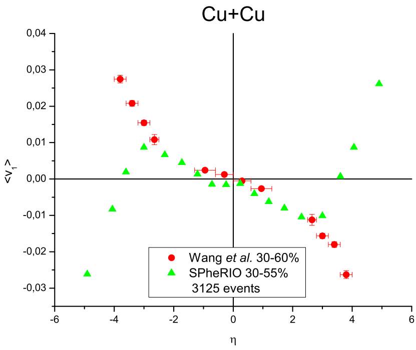
# NeXSPheRIO results

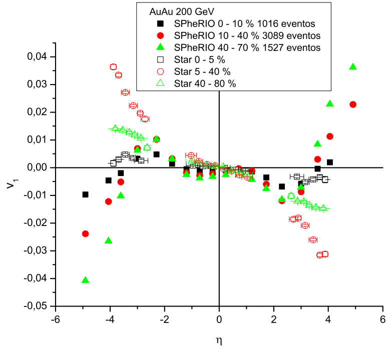
Qualitative agreement with PHOBOS for all $\eta$s

Quantitative agreement for $|\eta| < 3$

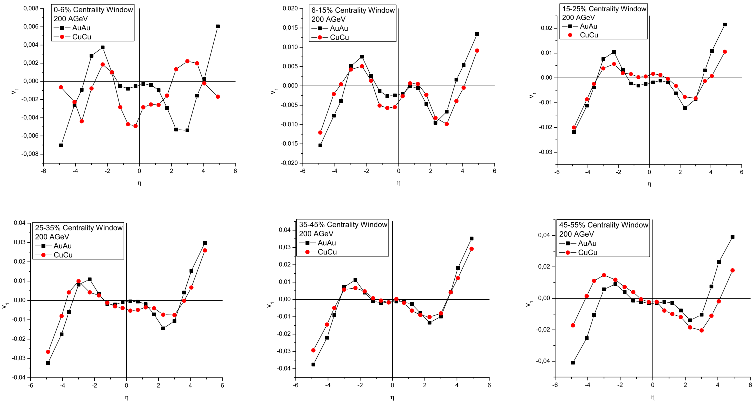


## Qualitative agreement with STAR for $|\eta| < 3$
## Turnover occurs for smaller $\eta$



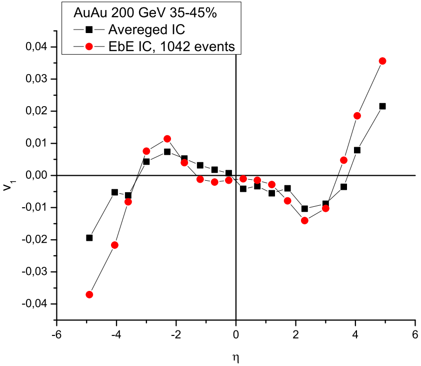
# $v_1(\eta)$ from NeXSpheRIO for various centrality windows for Au+Au and Cu+Cu at 200 A GeV (PRELIMIMARY)




- Little dependence on A in the windows 6-15% to 45-55%.
- Due to small A dependence of the tilt?
- Statistics must be improved.

## Effect of granularity

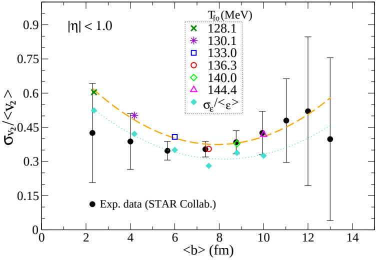
$v_1$ has a plateau for fluctuating initial conditions and a somewhat stronger negative inclination for smooth initial conditions (PRELIMINARY):

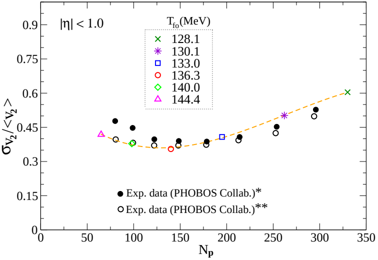



Due to cancellation between $v1$ from various events at $\eta \sim 0$?

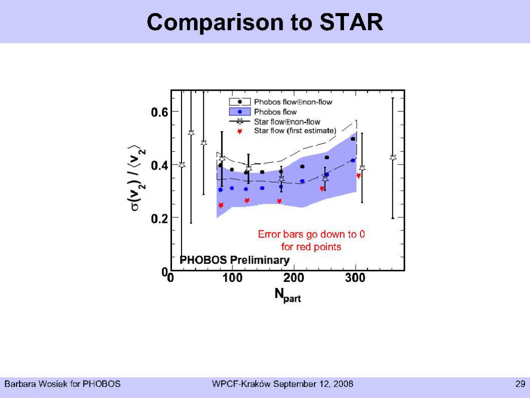
Quantities fluctuate a lot

Large $v_2$ fluctuations were predicted by NeXSPheRIO (C.E.Aguiar et al. Nucl.Phys. A698 (2002) 639c) and were found:



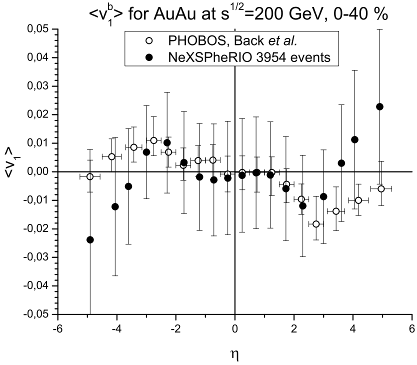



# More recent results from STAR and PHOBOS



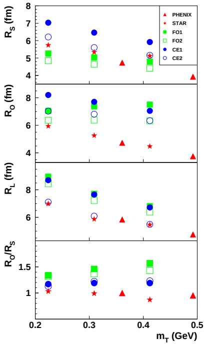

B.Wosiek WPCF 2008

## $v_1$ also fluctuates a lot:



- HBT

Hot tubes should manifest themselves giving smaller HBT radii



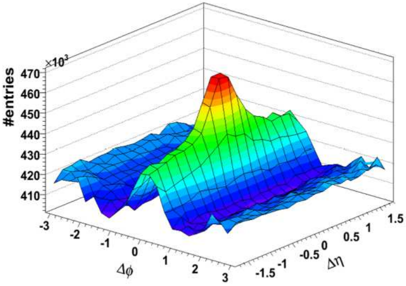

O.Socolowski Jr. et al. Phys.Rev.Lett. 93 (2004) 182301.

Open squares: EbE I.C, filled squares: averaged IC

In fact it might be more complicated

- Ridge effect

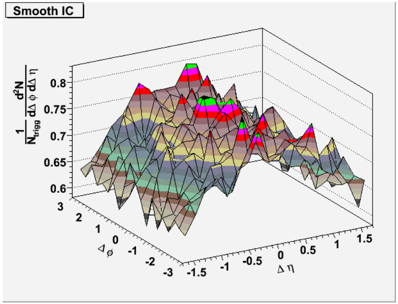
= structure seen in data on 2 particle correlations



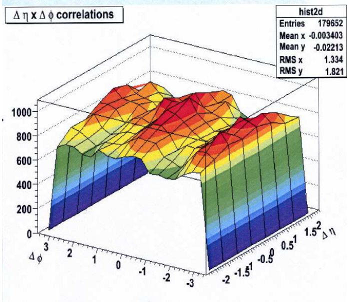

$\Delta\eta x \Delta\phi$ distribution of hadrons with $p_t^{assoc} > 2\,GeV$, associated with trigger hadrons with $3 < p_t^{trig} < 4\,GeV$ in central Au+Au collisions, J.Puthschke (STAR) QM06.

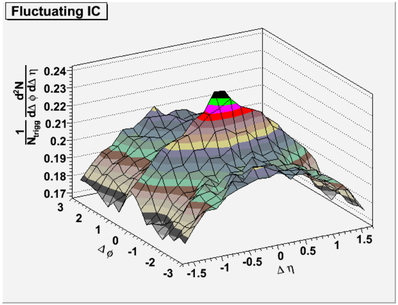
2 particle correlations are computed from NeXSpheRIO and treated with STAR methods (see talk by J.Takashi)

With averaged I.C.: no ridge



# EbE I.C.: one event (left), various events (right)



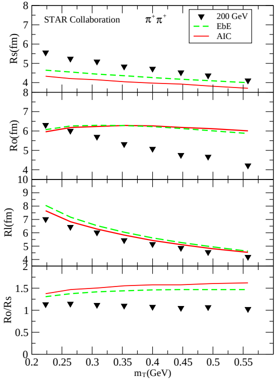

- For each event, hot tubes emit more high $p_t$ particles.
- The ridge is a summation effect from various events.
- The $\eta$ shape of the ridge is related to the initial conditions

# Summary

Can one see the effect of fluctuating I.C. in observables?

- high $p_t$ part of the $p_t$ spectra is lifted
- $v_2(p_t)$ is flatter
- $v_2(\eta)$ has no shoulder
- $v_1(\eta)$ has a plateau
- variables such as $v_2$ or $v_1$ fluctuate
- HBT radii: complicated
- tube structure may play a part in the ridge phenomena

# HBT radii with improved continuous emission



# Tube structure from NeXus alng the collision axis