NeXSPheRIO results on v_1 and v_2 at RHIC

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Outline

Objective

What is NeXSPheRIO?

Results for $\langle v_2 \rangle$

Results for $\langle v_1 \rangle$

Summary

Objective

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

Here: NeXSPheRIO results on Au+Au collisions and (less studied) Cu+Cu collisions.

Elliptic flow: average value, connection with eccentricity (cf. PHOBOS) and fluctuations.

Directed flow: average value and physical origin.

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- Smoothed Particle Hydrodynamics was 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

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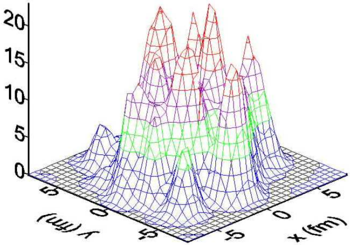
- Advantage: incorporates any geometry in the initial conditions

What is NeXSPheRIO?

NeXus is used to generate the initial conditions (IC)

[H.J. Drescher, F.M. Liu, S. Ostrapchenko, T. Pierog and K. Werner, *Phys. Rev.* **C65** (2002) 054902.]



$\eta = 0$ slice for initial energy density of a central RHIC collision with several high density peaks (in GeV/fm^{-3}). (In usual hydrodynamic approach, one assumes some highly symmetric and smooth IC.)

NeXSPheRIO is run many times and an average over final results is performed.

This mimics experimental conditions.

NeXSpheRIO has been used to study a range of problems:

- effect of fluctuating initial conditions on particle distributions C.E. Aguiar *et al.* Nucl.Phys. A**698** 639c (2002)
- energy dependence of the kaon effective temperature M. Gaździcki *et al.* Braz.J.Phys. **34** 322 (2004); Acta Phys. Pol. B**35** 179 (2004)
- interferometry at RHIC O. Socolowski Jr. *et al.* Phys.Rev.Lett., **93** 182301 (2004); Acta Phys. Pol. **B36** 347 (2005)
- transverse mass distributions at SPS for strange and non-strange particles F. Grassi *et al.* J.Phys. G**30** S1041 (2005)
- effect of the different theoretical and experimental binnings R.Andrade *et al.* Braz.J.Phys. **34** 319 (2004)
- effect of the nature of the quark-hadron transition and of the particle emission mechanism Y. Hama *et al.* QM05 proceedings, Nucl.Phys. A**774** 169 (2006)
- how to relate the hydro-computed and experimental $\langle v_2 \rangle$ R. Andrade *et al.*, Phys.Rev.Lett. **97** 202302 (2006)
- Strange particles at RHIC:W.L.Qian et al., arXiv:0709.0845
- $\langle v_2 \rangle$, $\langle v_1 \rangle$: this talk

The version of NeXSPheRIO used here has an eos with a critical point

Y. Hama *et al.* QM05 proceedings, Nucl.Phys. A**774** 169 (2006)

and incorporate strangeness conservation.

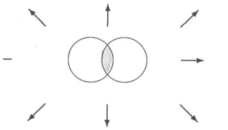
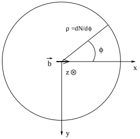
- Centrality windows are defined *as experimentally*, using participant number and not impact parameter R.Andrade *et al.* Braz.J.Phys. **34** 319 (2004)
- NeXus IC are normalized by an η-dependent factor to reproduce $dN_{ch}/d\eta$ in each centrality window (Au+Au) and most central windows (Cu+Cu)
- $T_{f.out}$ is fixed (mostly) by $dN_{ch}/p_t dp_t$ and depends on the centrality window (i.e. number of participants).

Results for $\langle v_2 \rangle$

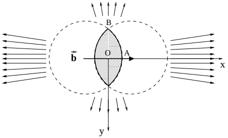
Why study $\langle v_2 \rangle$?

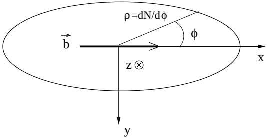
If a nucleus-nucleus collision

- 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

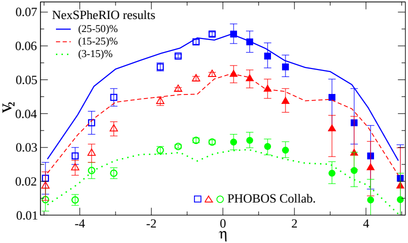


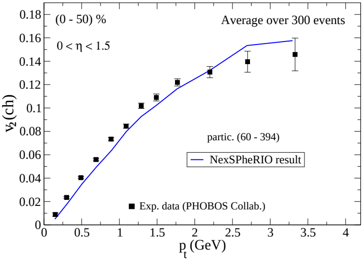


v_2 = measure of this stretching, so teaches about IC, thermalization, etc

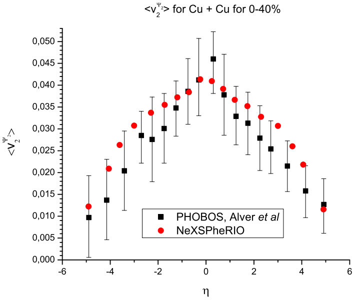
Elliptic flow is computed in the event plane and not reaction plane to compare with data R. Andrade *et al.*, Phys.Rev.Lett. **97** 202302 (2006)

Au+Au

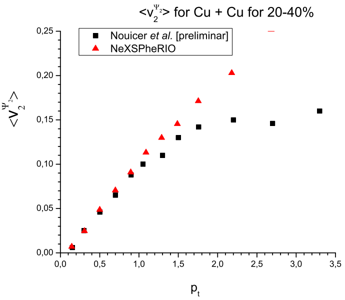




Cu+Cu



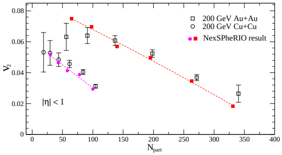
<v$_2^{\Psi_2}$> for Cu + Cu for 0-40%
<v$_2^{\Psi_2}$>
η
PHOBOS, Alver *et al*
NeXSPheRIO

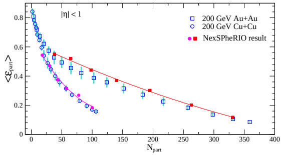


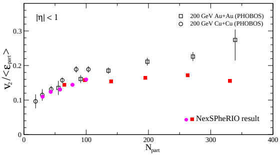
<v$_2^{\Psi_2}$> for Cu + Cu for 20-40%
<v$_2^{\Psi_2}$>
p$_t$
Nouicer *et al.* [preliminar]
NeXSPheRIO

Possible connection with participant eccentricity (PHOBOS)

Preliminary: in the region where they have similar N_{part}, Au+Au and Cu+Cu have similar $\langle v_2 \rangle / \langle \epsilon_{part} \rangle$. For large N_{part}, Au+Au has a flat $\langle v_2 \rangle / \langle \epsilon_{part} \rangle$. This strengthens the part played by $\langle \epsilon_{part} \rangle$ in $\langle v_2 \rangle$







Results for e-b-e quantities

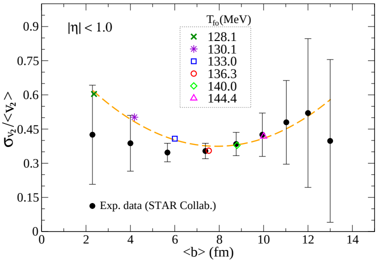
Why study v_2 fluctuations?

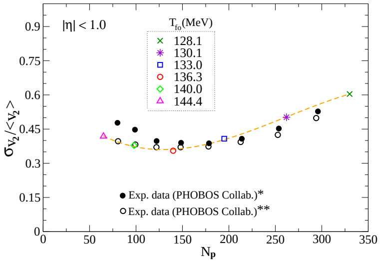
$\langle v_2 \rangle$ teaches about IC, thermalization, etc, on an average basis.

Fluctuations give information on an event-by-event basis.

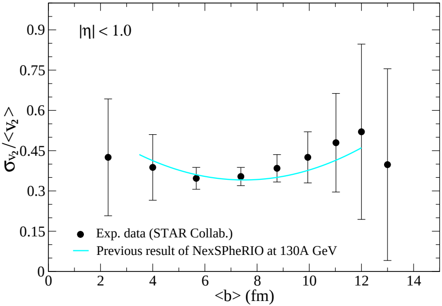
It is a more detailed tool.

v_2 fluctuations agree with (upper limit) from left) STAR and right) PHOBOS:



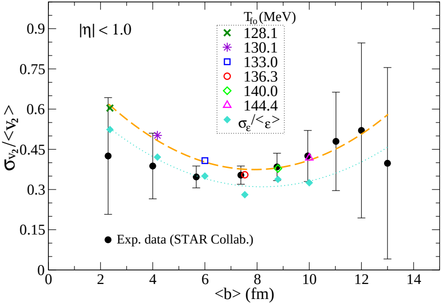


In fact, the correct order of magnitude of these fluctuations (at $\sqrt{s} = 130\,GeV$) was predicted by NeXSPheRIO C.E. Aguiar *et al.* Nucl.Phys. A**698** 639c (2002)



Where do these fluctuations come from?

Compare them with $\sigma_{\epsilon_{participant}} / \langle \epsilon_{participant} \rangle$.



Preliminary*:

$\sigma_{v_2}/\langle v_2 \rangle$ is a little higher than $\sigma_{\epsilon_{participant}}/\langle \epsilon_{participant} \rangle$

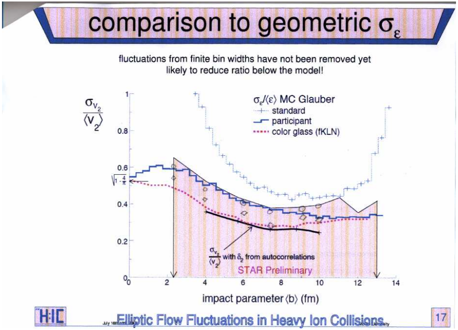
$\Rightarrow$ NeXus initial conditions are the main source of v_2 fluctuations.

*There are various ways of defining the eccentricity. So far it does not seem to have a strong influence, but we are still checking this point.

If the experimental upper limit on v_2 fluctuations decreases, our model and various outhers might be ruled out:

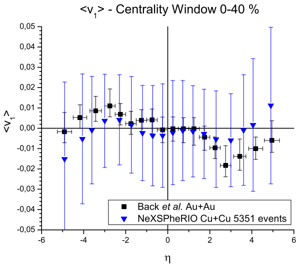
Picture adapted from P.Sorensen, Montreal meeting, july 2007,

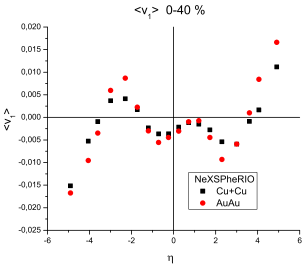
http://www.physics.mcgill.ca/etd-hic/schedule.html



Results for $\langle v_1 \rangle$

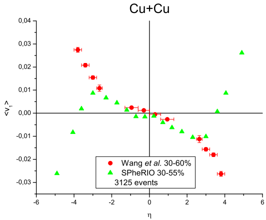
Our $v_1(\eta)$ is in agreement with PHOBOS and Au+Au and Cu+Cu are rather similar:





Our $v_1(\eta)$ does not have its turnover in agreement with STAR

(even after removing low p_T protons as suggested in B.B. Back et al. Phys. Rev. Lett. 97 (2006) 012301).



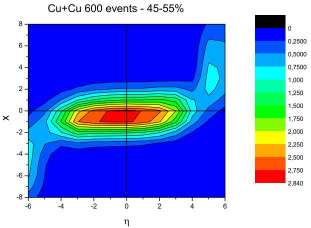
Preliminary: the wiggle in $v_1(\eta)$ comes from convolution of

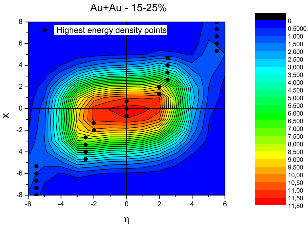
1) rapidity loss (left fig.)

(for η.0, projectile nucleons at negative x suffer more rapidity loss than those at positive x)

2) the highest initial energy density line has an inclination in relation to the collision axis (right fig.).

For small-medium positive η, negative x particles are more accelerated towards decreasing negative x than positive x particles are accelerated towards increasing positive x, causing in average a negative v_1. For small-medium negative η, in average v_1 is positive.





Summary

- Results from NeXSPheRIO are in agreement with RHIC charged particle data in the various centrality windows for $dN/d\eta$, $dN/p_t dp_t$, $v_2(\eta)$ and $v_2(p_t)$ for Au+Au and Cu+Cu.
- v_2 fluctuations from NeXSPheRIO agree with STAR and PHOBOS results.
  Preliminary: v_2 fluctuations from NeXSPheRIO come mostly from the I.C..
- If v_2 fluctuations data decrease, many models may have problems. $\Rightarrow$ v_2 fluctuations seem a good way to constrain models.
- Preliminary results on v_1 and its origin were shown.