Predictions for event-by-event flow harmonic distributions at RHIC

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Outline

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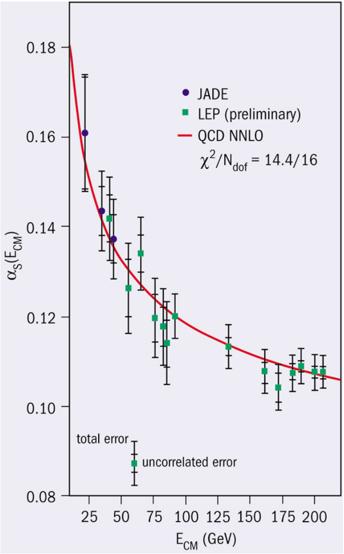
QGP Discovery

The Quark Gluon Plasma (QGP) was proposed in the 70's based on a now well known feature of the QCD (And other gauge theories) discovered by Gross, Wilczek and Politzer (2004 nobel). The discovery of the QGP was announced in 2005 at RHIC, and it was measeured also in the LHC.



http://cerncourier.com/cws/article/cern/29178

QCD Phase Diagram

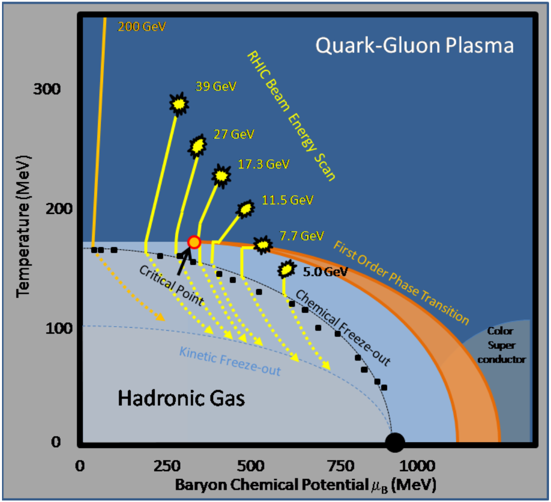


Figure: Phase Diagram Cartoon

Picture taken from: https://quark.phy.bnl.gov/ swagato/USQCD/

Motivation

- The standard description of the relativistic heavy ion collision can be divided roughly in 3 stages:
  - A model that supplies us with initial condition
  - The hydrodynamic stage.
  - The decoupling stage

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- The standard description of the relativistic heavy ion collision can be divided roughly in 3 stages:
  - A model that supplies us with initial condition
  - The hydrodynamic stage.
  - The decoupling stage
- Therefore, great part of the uncertainty in our models come from the fact that we do not fully understand the first stage of this description. [1]

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So, basically the objective is relate the final state (Which we can measure) with the initial conditions.

A bus that goes in a straight line with constant velocity arrives at Barra Funda at some time. From where it departed?

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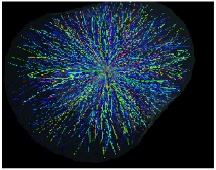
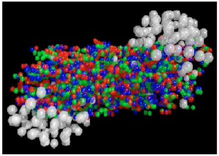
Our problem is similar:





?

Motivation

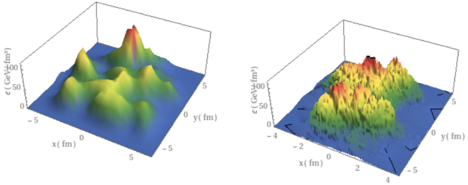


Figure: From left to right, Nexus and MC-KLN initial conditions. Both figures extracted from: F. G. Gardim, F. Grassi, P. Ishida, M. Luzum, P. S. Magalhães, J. Noronha-Hostler. Arxiv:1712.03912

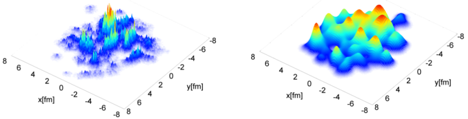


Figure: IP-GLASMA and MC-GLAUBER initial conditions. Extracted from: B. Schenke, P. Tribedy, R. Venugopalan. Arxiv: 1202.6646

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1. Introduction
   - Motivation
   - Flow Harmonic Distributions
   - Eccentricity ϵ_n
   - NeXSPheRIO
2. Results
   - LHC Energies
   - Prediction for RHIC top energy
     - Prediction isn't quite the word...
3. Summary and Conclusions

Flow Harmonic Distributions

- Particle distribution:

$$\frac{dN}{p_T dp_T d\phi dy} = \frac{dN}{2\pi p_T dp_T dy}\left[1 + \sum_{n=-\infty}^{\infty} v_n e^{i(n(\phi-\Psi_n))}\right] \tag{1}$$

Outline

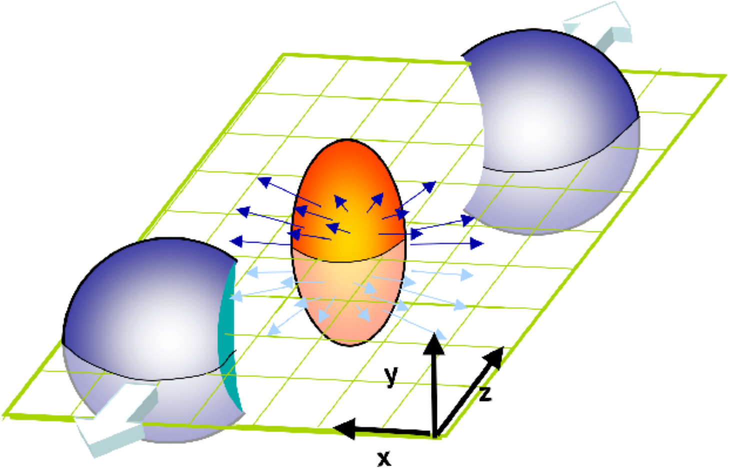

Figure taken from: Heinz U. in https://arxiv.org/pdf/0810.5529.pdf

Eccentricity ϵ_n

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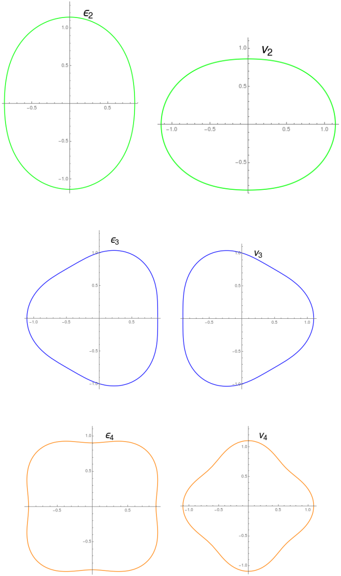
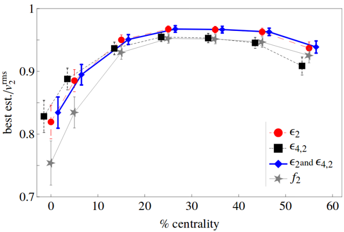
- With particular interest in the case $m = n$, which we call ϵ_n with $\Phi_{n,n} = \Phi_n$
- In a given centrality window, v_2 and v_3 are approximately for each event, proportional to ϵ_2 and ϵ_3 respectively. However there is deviations on this, for example: For larger v_2 this proportionality does not hold.

ϵ_n and v_n contributions



ϵ_n and v_n



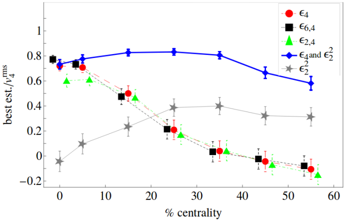


Figure: Extracted from: F.G. Gardim, F. Grassi, M. Luzum, J.Y. Ollitrault. Arxiv: 1111.6538

ϵ_n and v_n

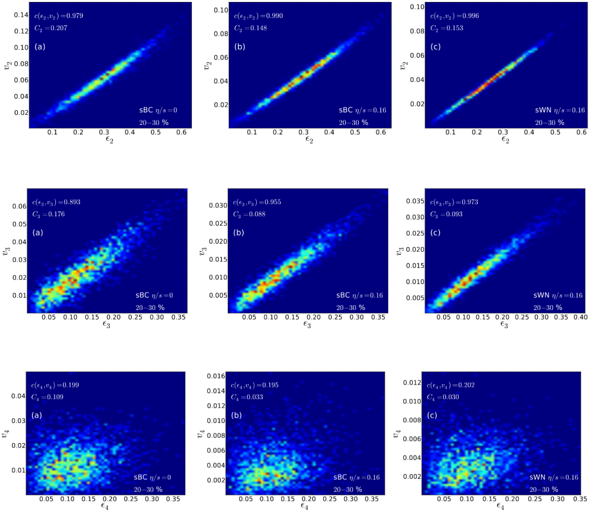


Figure: Extracted from: H. Niemi, G.S. Denicol, H. Holopainen and P. Huovinen. Arxiv:1212.1008

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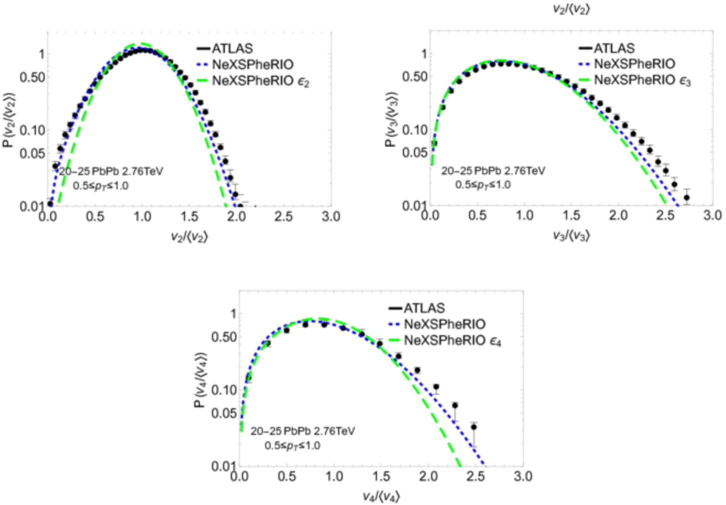
NeXSPheRIO

NeXus **S**moothed **P**article **h**ydrodynamic **e**volution of **R**elativistic heavy-**IO**n collisions

- NeXus generator initial conditions
- Perfect fluid hydrodynamics in 3+1 dimensions
- Isothermal Cooper-Frye freeze out

Outline

LHC



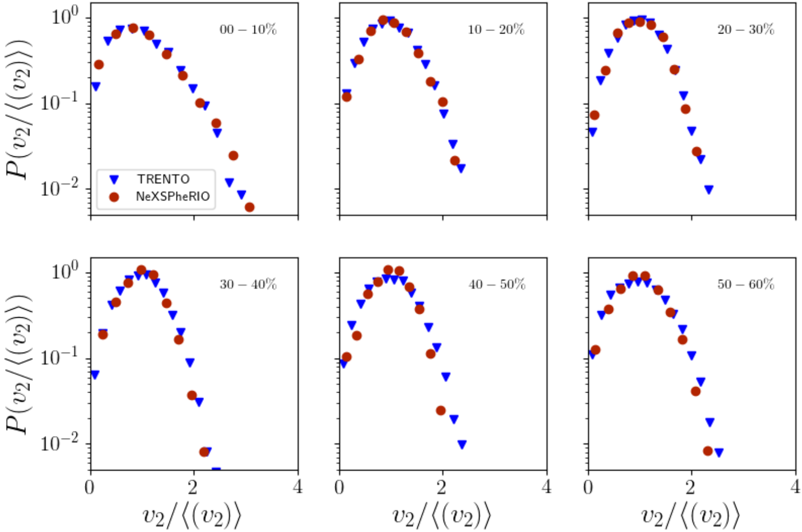
v2/⟨v2⟩
ATLAS
NeXSPheRIO
NeXSPheRIO ε2
P(v2/⟨v2⟩)
20–25 PbPb 2.76TeV
0.5≤pT≤1.0
v2/⟨v2⟩
ATLAS
NeXSPheRIO
NeXSPheRIO ε3
P(v3/⟨v3⟩)
20–25 PbPb 2.76TeV
0.5≤pT≤1.0
v3/⟨v3⟩
ATLAS
NeXSPheRIO
NeXSPheRIO ε4
P(v4/⟨v4⟩)
20–25 PbPb 2.76TeV
0.5≤pT≤1.0
v4/⟨v4⟩

Outline

RHIC

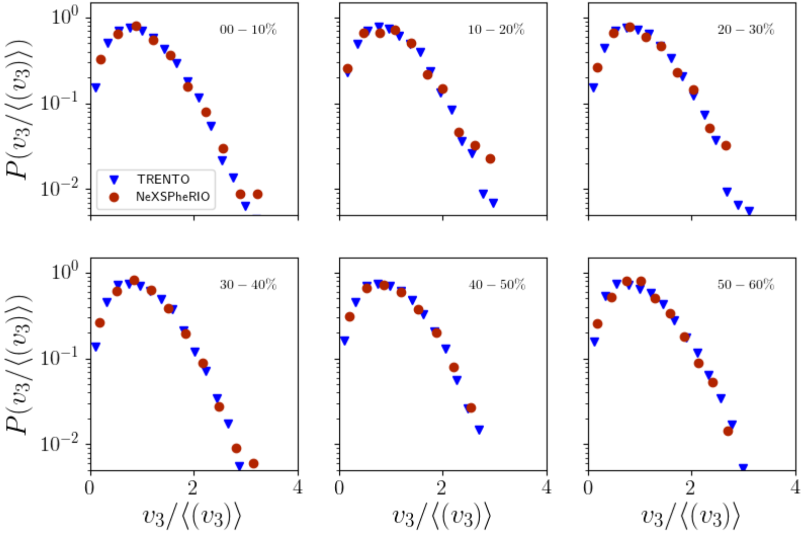
- TRENTO initial conditions
- V-USPHYDRO [3]
  - Viscous Hydrodynamics in 2+1 dimensions

RHIC



00 – 10%
10 – 20%
20 – 30%
30 – 40%
40 – 50%
50 – 60%
TRENTO
NeXSPheRIO
$P(v_2/\langle\langle v_2\rangle\rangle)$
$v_2/\langle\langle v_2\rangle\rangle$
10^0
10^{-1}
10^{-2}
0
2
4

RHIC



00 – 10%
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TRENTO
NeXSPheRIO
$P(v_3/\langle(v_3)\rangle)$
$v_3/\langle(v_3)\rangle$
10^0
10^{-1}
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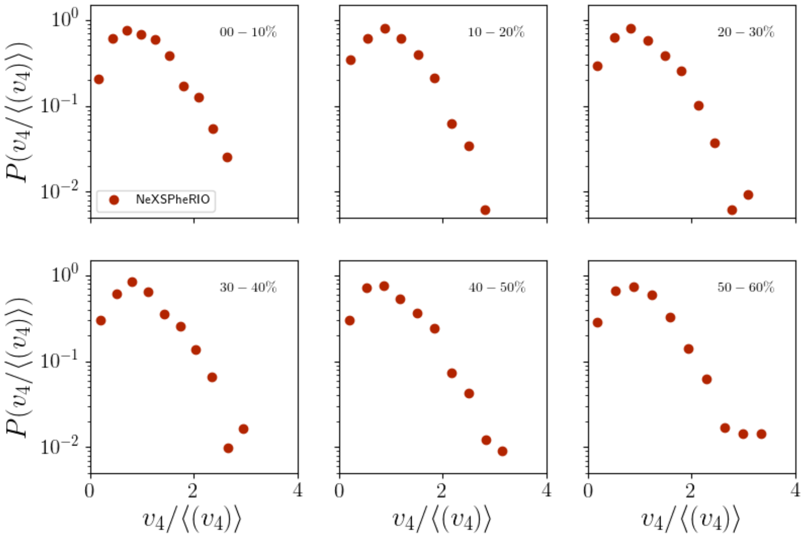
0
2
4

RHIC



10^0
10^{-1}
10^{-2}
$P(v_4/\langle(v_4)\rangle)$
00 – 10%
10 – 20%
20 – 30%
30 – 40%
40 – 50%
50 – 60%
NeXSPheRIO
0
2
4
$v_4/\langle(v_4)\rangle$

Prediction isn't quite the word...

Quark Matter 2017 Poster:

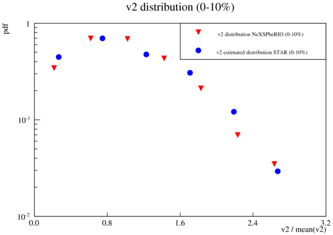
Event-by-Event Distributions of Flow Harmonics in U+U Collisions at $\sqrt{s_{NN}} = 193\text{GeV}$

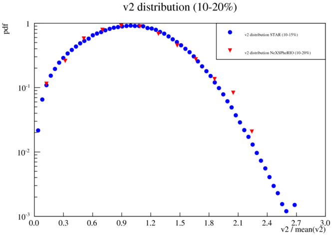
Maowu Nie, *for the STAR Collaboration*
Shanghai Institute of Applied Physics & Stony Brook University

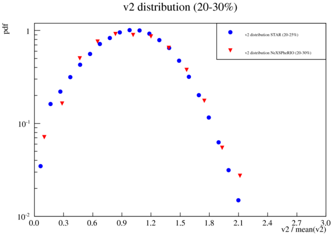
Abstract

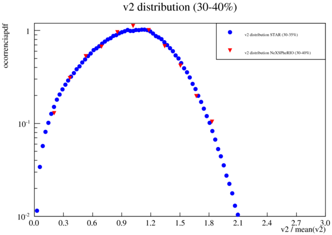
In this work, we present the study of Event-by-Event(EbyE) measurement of elliptic flow in U+U collisions with center-of-mass energy $\sqrt{s_{NN}} = 193\text{GeV}$ and in Au+Au collisions with $\sqrt{s_{NN}} = 200\text{GeV}$. A comparison between the asymmetric U+U and a symmetric Au+Au system is shown in terms of the probability distributions of flow vector. The measured flow vector distributions are unfolded by a data-driven Bayesian Unfolding process to suppress non-flow and statistic fluctuation to obtain the true flow distributions[1]. From the probability distribution ($p(v_2)$), multi-particle cumulants of v_2 - $v_2\{2\}$, $v_2\{4\}$ and $v_2\{6\}$ are calculated. Comparing to Au+Au, $v_2\{4\} > 0$ and $v_2\{6\} < 0$ in the most central U+U collisions indicates that the prolate shape of uranium increases the anisotropy in the final momentum space distributions of the observed particles. A splitting between $v_2\{6\}$ and $v_2\{4\}$ is observed for most centralities in Au+Au and U+U, which is a signature of non-Gaussian fluctuations.

Prediction isn't quite the word...









Summary and Conclusions

- I've presented the definitions and a simple way of calculating both v_n and ϵ_n
- As mentioned in the presentation: Harmonic flow scaled distributions are rather independent of viscosity and so, they should depend on initial conditions
- Also showed that in some cases eccentricity is a good way to estimate harmonic flow scaled distributions
- Various models of initial conditions are excluded by LHC flow distributions data (MC-KLN, MC-Glauber). However among the models that survive (e.g. TRENTO, NeXus) the predictions are fairly similar for RHIC top energy.

Bibliography

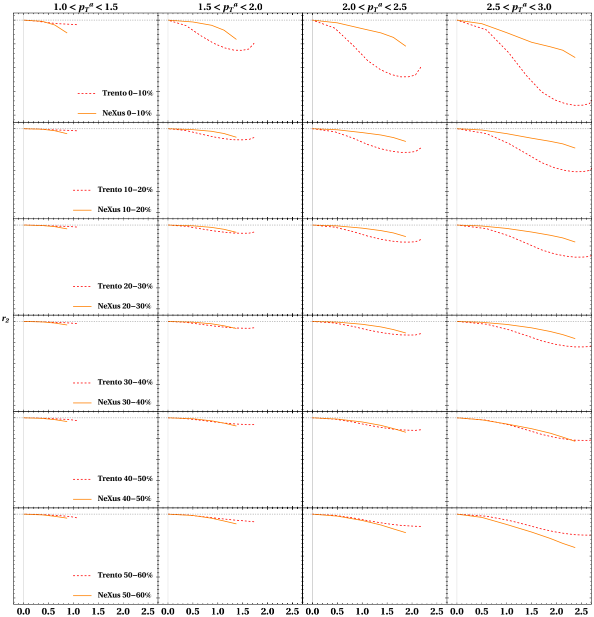
- Matthew Luzum and Paul Romatschke Phys. Rev. C 78, 034915, 2008
- F. G. Gardim, F. Grassi, M. Luzum, J.Y. Ollitrault Phys. Rev. C 85, 024908 (2012)
- J. Noronha-Hostler, J. Noronha, and F. Grassi Phys. Rev. C 90, 034907

Thank you for your attention

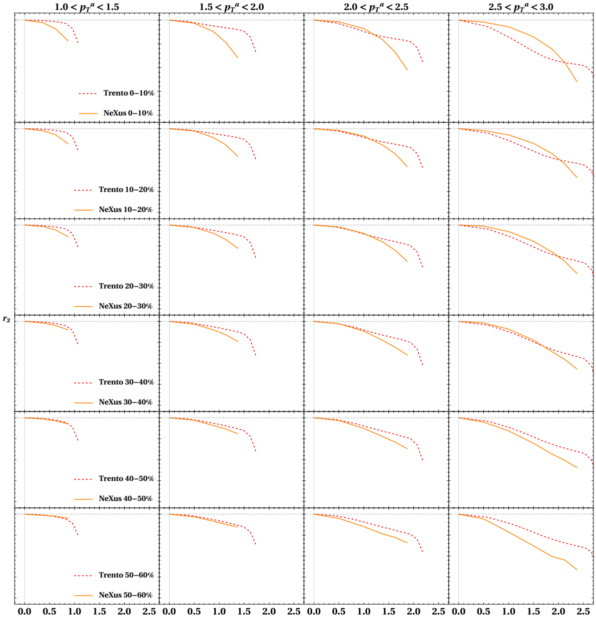
Let's go lunch!

BACKUP SLIDES

Extra slide 1



Extra slide 2



Flow Harmonic Distributions

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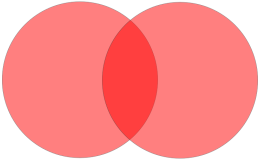

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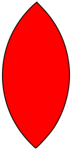

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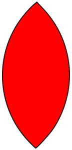

- Other v_n contributions can be explained by the granularities on the initial conditions.

Flow Harmonic Distributions

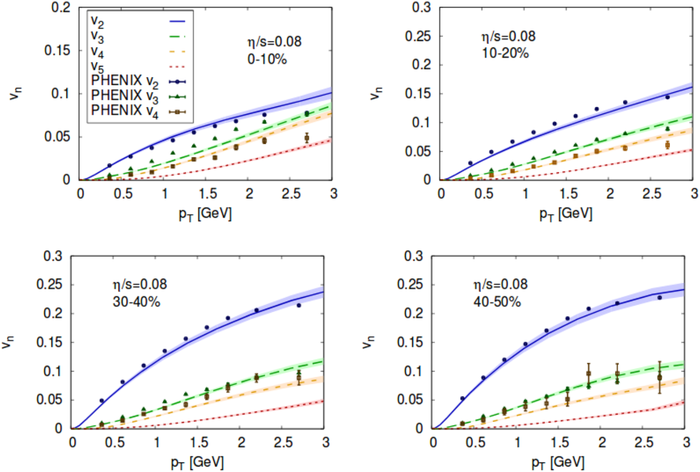

Figure: $v_n(p_T)$ with $\eta/s = 0.08$ extracted from: B.Schenke, S. Jeon and C. Gale arxiv: 1109.6289, experimental data from PHENIX

Flow Harmonic Distributions

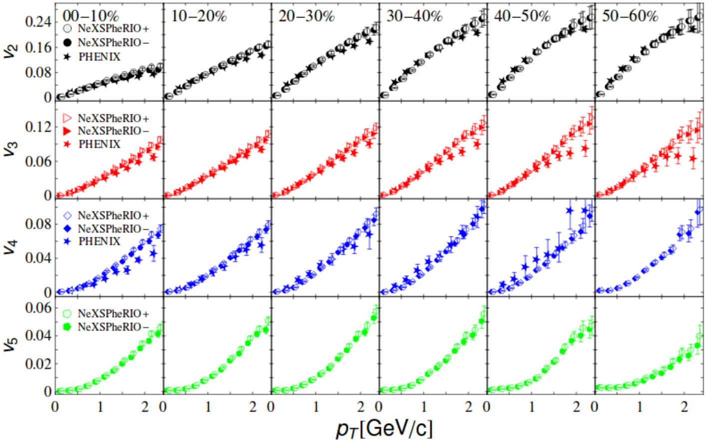

Figure: $v_n(p_T)$ with perfect hydro extracted from F.G. Gardim, F. Grassi, M. Luzum and J.Y. Ollitrault arxiv: 1203.2882, experimental data from PHENIX.