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

Leonardo Barbosa

Instituto de Física
Universidade de São Paulo

2018
1 Introduction
   • Motivation
   • Flow Harmonic Distributions
   • Eccentricity $\epsilon_n$
   • NeXSPheRIO

2 Results
   • LHC Energies
   • Prediction for RHIC top energy
     • Prediction isn’t quite the word...

3 Summary and Conclusions
Introduction

Motivation

Flow Harmonic Distributions

Eccentricity $\epsilon_n$

NeXSPheRIO

Results

LHC Energies

Prediction for RHIC top energy

Prediction isn’t quite the word...

Summary and Conclusions
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 measured also in the LHC.

http://cerncourier.com/cws/article/cern/29178
Figure: Phase Diagram Cartoon

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

- 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]
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?
Motivation

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?

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
1 Introduction
   - Motivation
   - Flow Harmonic Distributions
     - Eccentricity $\epsilon_n$
     - NeXSPheRIO

2 Results
   - LHC Energies
   - Prediction for RHIC top energy
     - Prediction isn’t quite the word...

3 Summary and Conclusions
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

1. Introduction
   - Motivation
   - Flow Harmonic Distributions
   - Eccentricity $\epsilon_n$
   - NeXSPheRIO

2. Results
   - LHC Energies
   - Prediction for RHIC top energy
     - Prediction isn’t quite the word...

3. Summary and Conclusions
Figure taken from: Heinz U. in https://arxiv.org/pdf/0810.5529.pdf
Eccentricity $\epsilon_n$

- We can define the eccentricities (On the initial conditions) with their corresponding orientation angle $\Phi_{m,n}$:
Eccentricity $\epsilon_n$

- We can define the eccentricities (On the initial conditions) with their corresponding orientation angle $\Phi_{m,n}$:

$$\epsilon_{m,n} e^{in\Phi_{m,n}} = -\frac{\int r dr d\phi r^m e^{i\phi} \rho(r, \phi)}{\int r dr d\phi r^m \rho(r, \phi)}$$  (2)
We can define the eccentricities (On the initial conditions) with their corresponding orientation angle $\Phi_{m,n}$:

$$\epsilon_{m,n}e^{in\Phi_{m,n}} = -\frac{\int rdrd\phi r^m e^{in\phi} \rho(r, \phi)}{\int rdrd\phi r^m \rho(r, \phi)}$$  \hspace{1cm} (2)

With particular interest in the case $m = n$, which we call $\epsilon_n$ with $\Phi_{n,n} = \Phi_n$. 
Eccentricity $\epsilon_n$

- We can define the eccentricities (On the initial conditions) with their corresponding orientation angle $\Phi_{m,n}$:

$$\epsilon_{m,n} e^{i n \Phi_{m,n}} = - \frac{\int rdrd\phi r^m e^{i n \phi} \rho(r, \phi)}{\int rdrd\phi r^m \rho(r, \phi)}$$

(2)

- With particular interest in the case $m = n$, which we call $\epsilon_n$ with $\Phi_{n,n} = \Phi_n$

- In a given centrality window, $\nu_2$ and $\nu_3$ are approximately for each event, proportional to $\epsilon_2$ and $\epsilon_3$ respectively. However there is deviations on this, for example: For larger $\nu_2$ this proportionality does not hold.
$\epsilon_n$ and $v_n$ contributions
\( \epsilon_n \) and \( \nu_n \)

Figure: Extracted from: F.G. Gardim, F. Grassi, M. Luzum, J.Y. Ollitrault. Arxiv: 1111.6538
$\epsilon_n$ and $\nu_n$

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

1 Introduction
   - Motivation
   - Flow Harmonic Distributions
   - Eccentricity $\epsilon_n$
   - NeXSPheRIO

2 Results
   - LHC Energies
   - Prediction for RHIC top energy
     - Prediction isn’t quite the word...

3 Summary and Conclusions
NeXSPheRIO

NeXus Smoothed Particle hydrodynamic evolution of Relativistic heavy-IOn collisions

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

1 Introduction
   - Motivation
   - Flow Harmonic Distributions
   - Eccentricity $\epsilon_n$
   - NeXSPheRIO

2 Results
   - LHC Energies
   - Prediction for RHIC top energy
     - Prediction isn’t quite the word...

3 Summary and Conclusions
Introduction

- Motivation
- Flow Harmonic Distributions
- Eccentricity $\epsilon_n$
- NeXSPheRIO

Results

- LHC Energies
- Prediction for RHIC top energy
  - Prediction isn’t quite the word...

Summary and Conclusions
- TRENTO initial conditions
- V-USPHYDRO [3]
  - Viscous Hydrodynamics in 2+1 dimensions
Predictions for event-by-event flow harmonic distributions at RHIC.
Predictions for event-by-event flow harmonic distributions at RHIC
Prediction isn’t quite the word...

Quark Matter 2017 Poster:

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

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 $\sqrt{s_{\text{NN}}} = 193\text{GeV}$ and in Au+Au collisions with $\sqrt{s_{\text{NN}}} = 200\text{GeV}$. 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...

v2 distribution (0-10%)

v2 distribution (10-20%)

v2 distribution (20-30%)

v2 distribution (30-40%)
I’ve presented the definitions and a simple way of calculating both $v_n$ and $\epsilon_n$

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.


Thank you for your attention

Let’s go lunch!
BACKUP SLIDES
Leonardo Barbosa (USP)  Predictions for event-by-event flow harmc
An important contribution to $v_2$ is the initial spatial anisotropy produced by the geometry of the overlap region in the collision.
An important contribution to $v_2$ is the initial spatial anisotropy produced by the geometry of the overlap region in the collision.
An important contribution to $v_2$ is the initial spatial anisotropy produced by the geometry of the overlap region in the collision.
An important contribution to $v_2$ is the initial spatial anisotropy produced by the geometry of the overlap region in the collision.

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
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.