Constraining initial stages of heavy-ion collisions from RHIC and LHC data*

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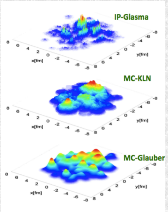
Abstract

We propose a systematic approach for constraining models of initial conditions using a combined analysis of elliptic v_2 and triangular v_3 flow data with viscous hydrodynamic calculations. For v_2 and v_3 harmonics, the hydrodynamic response to the initial state is dominated by the linear response, which means that v_2 is proportional to the ellipticity ε_2 and v_3 is proportional to the triangularity ε_3, i.e. $v_n = C_n\varepsilon_n$, where C_n is the linear response coefficient. Experimental data on elliptic and triangular flows, combined with the calculation of C_n in relativistic hydrodynamics, provide us the rms values of initial anisotropies ε_2 and ε_3. By varying free parameters in hydrodynamic calculations, we get an allowed region in the (rms ε_2, rms ε_3) plane. Thus we are able to compare Monte Carlo models of the initial state with the allowed region and exclude several of these models. We provide a simple test that can be performed on any candidate model to determine its compatibility with data. We also illustrate that the effect of changing the granularity of the initial state is similar to changing the medium properties, making these effects difficult to disentangle using only these data.

Initial conditions

Subject of study: initial energy-density profile



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• Glauber models:

MC-Glauber

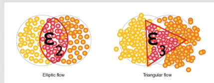
• QCD-inspired models:

MC-KLN
MCrcBK
IP Glasma
DIPSY

Methodology

Ellipticity and triangularity

Originates from the elliptic shape of the overlap area



Generated by fluctuations

Participant eccentricity

$$\varepsilon_n = \frac{\left|\int e(r,\varphi)\, r^n e^{in\varphi}\, r\, dr\, d\varphi\right|}{\left|\int e(r,\varphi)\, r^n\, r\, dr\, d\varphi\right|}$$

Hydro response to the initial state is linear:

$$v_n = \left(\frac{v_n}{\varepsilon_n}\right)_{hydro} \varepsilon_n$$

experimental data rms, average over events — hydro const

We can extract ε_2 and ε_3! → rms

Hydrodynamic modeling

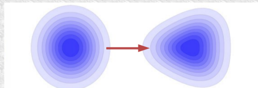
Our calculation is a 2+1D viscous hydrodynamic uses as initial condition the transverse energy density ($\epsilon(r,\phi)$) profile from an optical Glauber model.

- Initial conditions
- Relativistic hydro evolution
- Hadronization

Each step gives uncertainties!

For $(v_3/\varepsilon_3)_{hydro}$ the profile is deformed:

$$\epsilon(r,\phi) \rightarrow \epsilon\left(r\sqrt{1+\varepsilon'_3 \cos 3(\phi-\Psi_3)}, \phi\right)$$



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Hydrodynamic modeling uncertainties

Main uncertainty in the hydro evolution

The value of the shear viscosity of the strongly-interacting quark-gluon plasma.

We vary viscosity/entropy η/s: from 0 to 0.24 in steps of 0.04

Free parameters in initial conditions

1) Definition of the eccentricity: energy-density weighting or entropy density weighting

2) Thermalization time t_0: from 0.5fm/c to 1fm/c

2a) Starting temperature T_{start} and

2b) Freezeout temperature T_{fr} in order to fit Multiplicity and $\langle p_T \rangle$ from experimental data

Freezeout

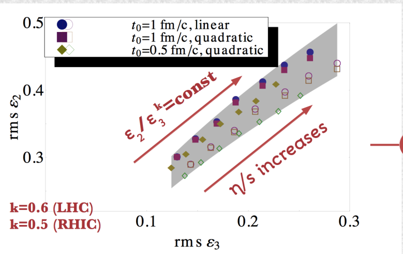
Viscous correction:

dependence on momentum p is unknown.

$$\frac{dN}{dp} = f_0(p)\left(1+\chi(p)\frac{1}{p^2} p^\mu p^\nu \pi^{\mu\nu}\right)$$

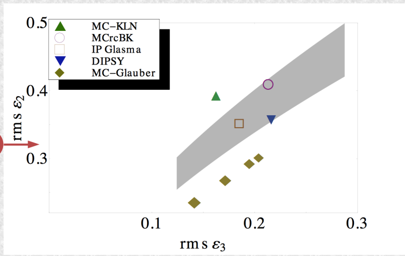
We test two possible ansatzs: linear $\chi(p) \propto p$ and quadratic $\chi(p) \propto p^2$

Results of hydrodynamic calculations



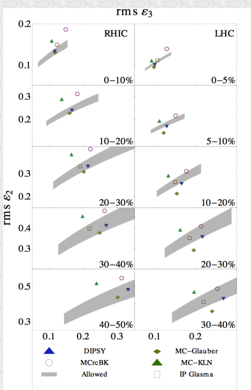
Values of (ε_2 , ε_3) spanned by hydrodynamic calculations, in combination with ALICE data for the 30-40% centrality bin at Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.

Constrain models



The MC-Glauber model is shown for different values of the width of gaussian σ=0 fm, 0.4 fm, 0.8 fm and 1.2 fm, which are distinguished by different symbol sizes, showing that changing the smearing parameter has the same effect as changing viscosity.

All centralities



Conclusions

- We have extracted ellipticity rms ε_2 and triangularity rms ε_3, using experimental data and hydro calculations with different sources of uncertainties and created a narrow allowed region on the (rms ε_3, rms ε_2) plane
- We have shown that we are able to constrain some of the models of initial state.
- It was shown that we can exclude MC-Glauber and MC-KLN models for LHC and MC-KLN and MCrcBK models for RHIC
- We have illustrated for the MC Glauber model that changing the granularity of the initial condition model has the same effect as changing viscosity, so the effects are difficult to disentangle.

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