Fluctuations in Ultra-Central Heavy-Ion Collisions

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Outline

Ultra-central Flow Puzzle -
The existing models can't give us accurate results for 0 − 1% cent. bin or more central.

Goal –
Find what fluctuations of initial stage are necessary to describe the final obsrevables.

Assumptions -
→ Anisotropies only from fluctuations.
→ $v_n\{2\} = K_n * \varepsilon_n\{2\}$
→ K_n depends on hydro parameters.
→ Local and small fluctuations

Method –
- Constrain the correlations to fluctuations of energy density $\delta\rho$

$$\langle \delta\rho(x_1)\, \delta\rho(x_2) \rangle = \kappa_2(x_1) * \delta(x_1 - x_2)$$

- Relation between fluctuations and Anisotropies.

(Grönqvist et al. - arXiv:1604.07230)

- Parameterization of the fluctuations By a power law $\kappa_2 = C^2 * \kappa_1^{2p}$

CONST. VISCOSITIES
→ K_n is a function only of η/s
→ p tuned by hand.
→ C and viscosities from the least square method.

RESULTS -
→ Reasonable fit for ultra-central results.

TEMP. DEPENDENCE
→It was used the JETSCAPE Parameterization to $\mathbf{K_n}$.
(JETSCAPE col.arXiv:2011.01430)
→Gaussian Process emulation
→Minimum χ^2

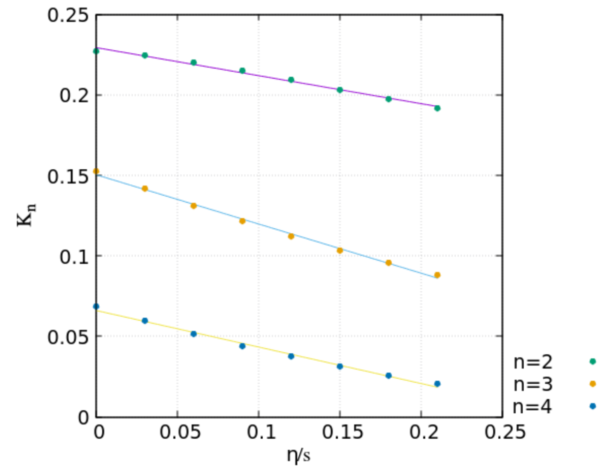
RESULTS -
→Good fit for $v_n\{2\}$.
→Fluctuations smaller in non-central region than η/s constant approach.

Response Coefficient - Constant viscosity case

- The assumption that the viscosities are constant and $K_n \equiv K_n(\eta/s)$ is the most naive choice and we started with it. We made some hydro evolutions by MUSIC and we obtained expressions to K_n.
- Parallel to that, we looked for expressions to $\epsilon_n\{2\}$ as proposed by Grönqvist et al. in (arXiv:1604.07230) and using the power parameterization to κ_2:

$$\epsilon_n\{2\} = \sqrt{\frac{\int_{x,y} r^{2n}\kappa_2(x,y)}{(\int_{x,y} r^n\kappa_1(x,y))^2}} = C \cdot \sqrt{\frac{\int_{x,y} r^{2n}\kappa_1(x,y)^{2p}}{(\int_{x,y} r^n\kappa_1(x,y))^2}}$$

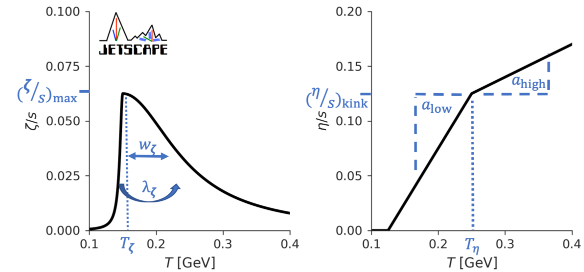
  The parameter p is put *by hand* the values of p, and the parameter C, togheter with the shear to s ratio $\frac{\eta}{s}$ are given by the application of the least square method.
- So, tunning the value of p, we can obtain the best value of $v_n\{2\}$ with χ^2 as a selection criteria.
- This apporach gave us reasonable values of $v_n\{2\}$ but we thought to use a more realistic approach, including a temperature dependence over the viscosities, as well a dependence on other hydro parameters over K_n. For this other approach, we have used a parametrization of the viscosities, as it will be shown in the following.

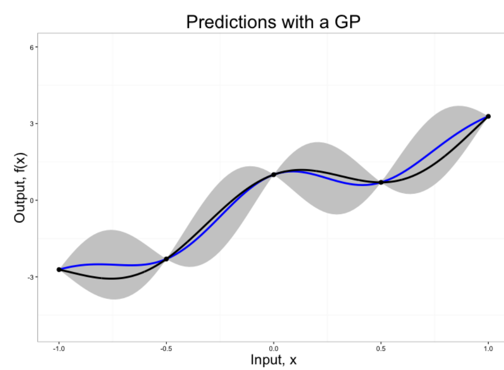


Response coefficients, calculated by MUSIC with the ALICE experimental cuts ($|\eta| < 0.8$ and $0.2 < p_T < 3.0GeV$), in terms of $\frac{\eta}{s}$. The linear regression is a good fit as we can see in this plot.

Response Coefficient - Thermal dependent case

- We used the same parameterization of K_n used in a JETSCAPE bayesian analysis paper (arXiv:2011.01430), $K_n \equiv K_n(\frac{\eta}{s}(T), \frac{\zeta}{s}(T), \tau_R, \ldots)$. In this definition, the viscosities are parameterized in terms of T and some coefficients $(a_{low}, a_{high}, T_\eta, (\frac{\eta}{s})_{kink}, (\frac{\zeta}{s})_{max}, T_\zeta, \omega_\zeta, \lambda_\zeta)$ and the K_n was calculated using the Grad's method correction to viscous correction.
- Since we have several parameters, we need a lot of values of K_n. Thus, it is a *sine qua non* condition to use an emulation process to get the behaviour of K_n from few direct calculations, called **design points**. These ones were got from an extrapolation of the K_n values from other centralities.
- Thus once we have the mapping of K_n, we can calculate $v_n\{2\}$ from the relation $v_n\{2\} = K_n \cdot \epsilon_n\{2\}$, where $\epsilon_n\{2\}$ is calculated from equation presented earlier and we calculated κ_2 by the power parametrization. We also calculated $v_n\{2\}$ directly from $T_R ENTO + JETSCAPE$ results.
- In order to get the best values of $v_n\{2\}$, we calculated them many times with all the parameters given by a Monte-Carlo sampling and using χ^2 as selection criteria again.

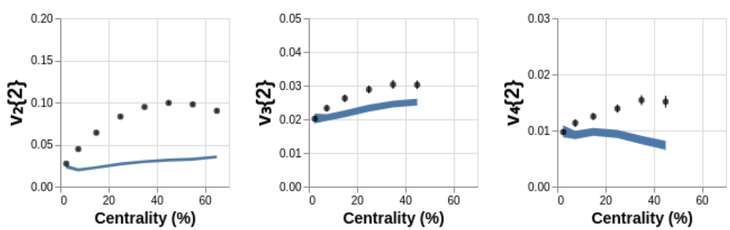




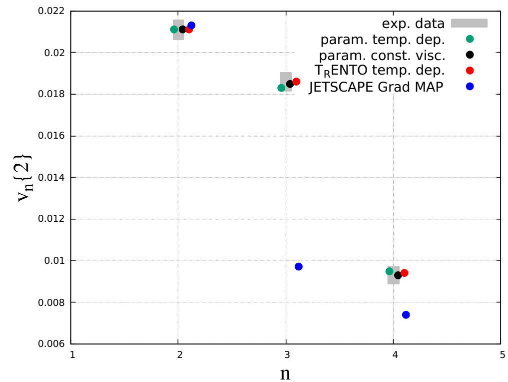
The black line is the function used as test. The blue line is the emulator results and the shaded region are the emulator uncertainties.

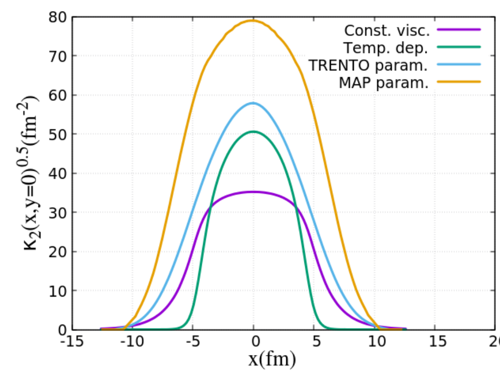
Results

- It is possible to obtain the ultra-central $v_n\{2\}$ values by three approaches presented here.
- The $T_R ENTO + JETSCAPE$ approach gave us good results to $v_n\{2\}$ from ALICE $0 - 1\%$ cent. bin data but only with parameters that give a very poor fit to all other centralities, as we can see on the plot below.



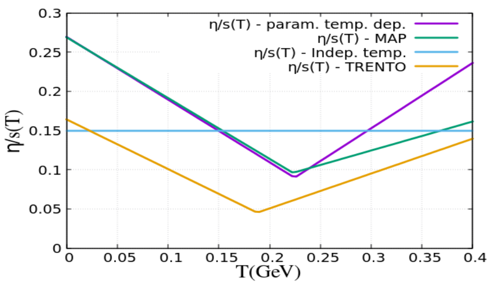
- Besides, we can see on the right plot that the fluctuations must be smaller than we work in other centralities. (the blue line shows the behaviour of the fluctuations when we use the MAP parameters, which don't give us accurate $v_n\{2\}$ results.

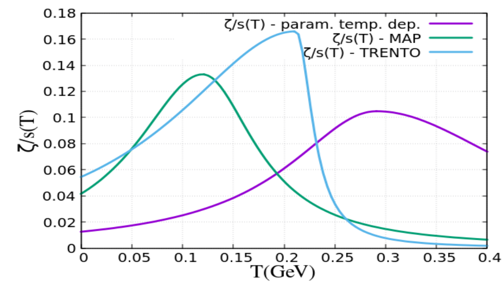




Results

The viscosities that give us the best results for $v_n\{2\}$.





The behaviour of η/s in terms of temperature. The purple line is the result from power parameterization of the fluctuations and JETSCAPE parameterization of $\frac{\eta}{s}(T)$. The blue line comes from constant shear viscosity. The green line comes from the MAP (maximum a posteriori) parameters relative to other centralities. The orange line is the result when we use T_RENTO parameters, instead the power parameterization, combined to JETSCAPE parameterization of $\frac{\eta}{s}(T)$.

The behaviour of ζ/s in terms of temperature. The purple line is the result from power parameterization + JETSCAPE parameterization of $\frac{\zeta}{s}(T)$. The blue line is the result when we use T_RENTO parameters, instead the power parameterization, combined to JETSCAPE parameterization. The green line is the value of ζ/s when we use the MAP (maximum a posteriori) parameters calculated from other centralities. It's important no notice that these last ones don't give us reasonable results for v_n.