Anisotropic flows and the shear viscosity of the QGP within a transport approach with initial state fluctuations

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We study the build up of elliptic flow and high order harmonics v_n within a transport approach at fixed shear viscosity to entropy density ratio and with initial state fluctuations. We show, exploring the T dependence of η/s, that a study of v_n in a wide p_T range allows to understand the difference behind the collective flows at LHC respect to RHIC. In particular we study the effect of a temperature dependent η/s at different beam energies from RHIC for Au+Au at √s=62.4, 200 GeV to LHC energies for Pb+Pb at √s=2.76 TeV. We find that for the different beam energies considered the suppression of the elliptic flow due to the viscosity of the medium has different contributions coming from the hadronic or QGP phase depending on the average energy of the system.

1- Kinetic theory at fixed η/s

$$p^{\mu}\partial_{\mu} f(X,p) = C_{22}$$

Numerically we use the test partile method and for the collision integral we use the stochastic algorithm.
Z. Xu and C. Greiner, PRC 71 064901 (2005).

$$C_{22}=\frac{1}{2E_1}\int\frac{d^3p_2}{(2\pi)^3 2E_2}\frac{1}{\nu}\int\frac{d^3p'_1}{(2\pi)^3 2E'_1}\frac{d^3p'_2}{(2\pi)^3 2E'_2} f'_1 f'_2 \left|M_{1'2'\to 12}\right|^2 (2\pi)^4\delta^{(4)}(p'_1+p'_2-p_1-p_2)$$

To fix locally η/s we need to know η/s ↔ σ(θ),M,T → Chapman-Enskog approximation

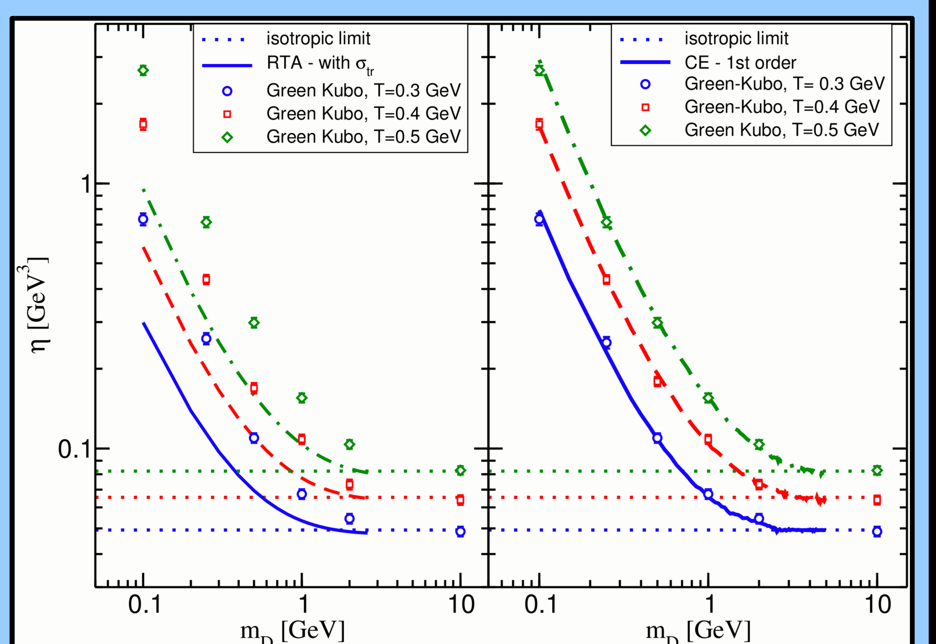
$$\frac{d\sigma}{dt}\sim\frac{\alpha_s^2}{(t-m_D^2)^2} \qquad \sigma_{tr}=\int d\Omega \sin^2(\theta_{cm})\frac{d\sigma}{d\Omega_{cm}}=\sigma_{tot} f(a)\leq\frac{2}{3}\sigma_{tot}$$

Chapman-Enskog approximation

$$[\eta]_{1st}/s=\frac{1}{15}\langle p\rangle\tau_\eta=\frac{1}{15}\frac{\langle p\rangle}{\sigma_{tot}\, g(a)\,\rho}$$

$$g(a)=\frac{1}{50}\int_0^\infty dy\, y^6\left[\left(y^2+\frac{1}{3}\right)K_3(2y)-yK_2(2y)\right]f(a), \quad a=\frac{m_D}{2T}$$

Chapman-Enskog is a good approximation already at I° order ≈ 5% (≈ 3% at II° order)



S. Plumari, A. Puglisi, F. Scardina, V. Greco, PRC 86 (2012) 054902.
S. Plumari et al., J.Phys.Conf.Ser. 420 (2013) 012029

Simulating a fixed η/s

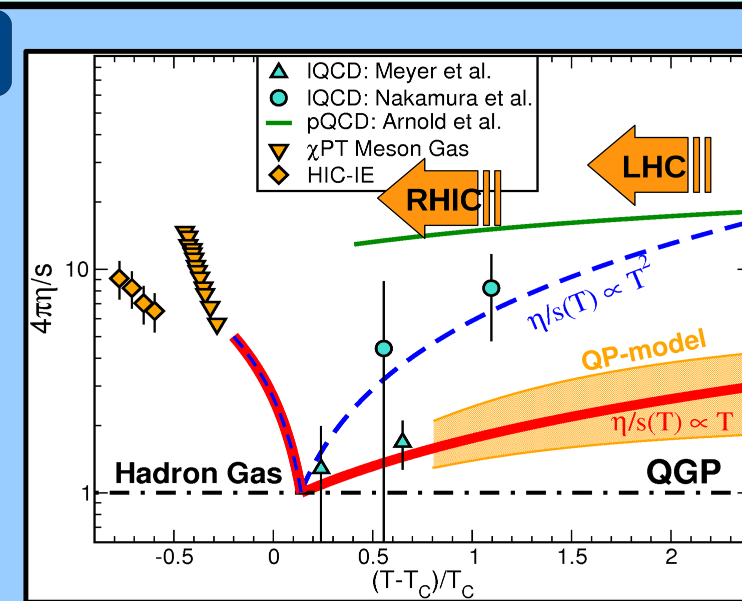
$$\eta(\vec{x},t)/s=\frac{1}{15}\langle p\rangle\tau_\eta \rightarrow \sigma_{tot}^{\eta/s}=\frac{1}{15}\frac{\langle p\rangle}{g(m_D/2T)\,n}\frac{1}{\eta/s}$$

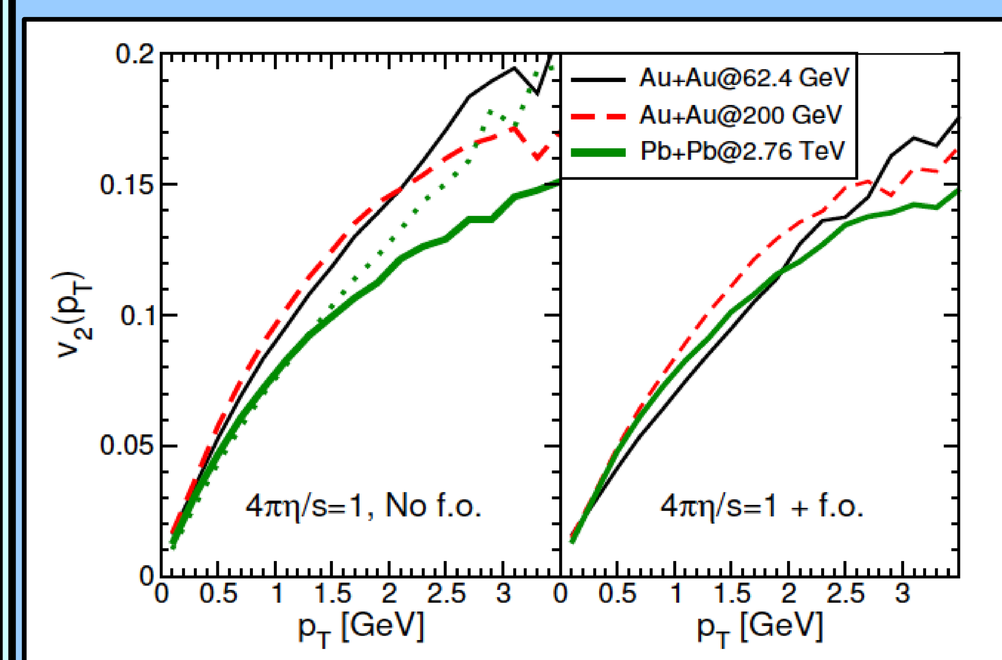
Instead of focusing on specific microscopic calculations we fixes the total cross section in order to have the wanted η/s. Similar to D. Molnar, arXiv:0806.0026[nucl-th]

σ is evaluated in each cell of the coordinate space of our grid during the dynamics according the Chapman - Enskog equation.

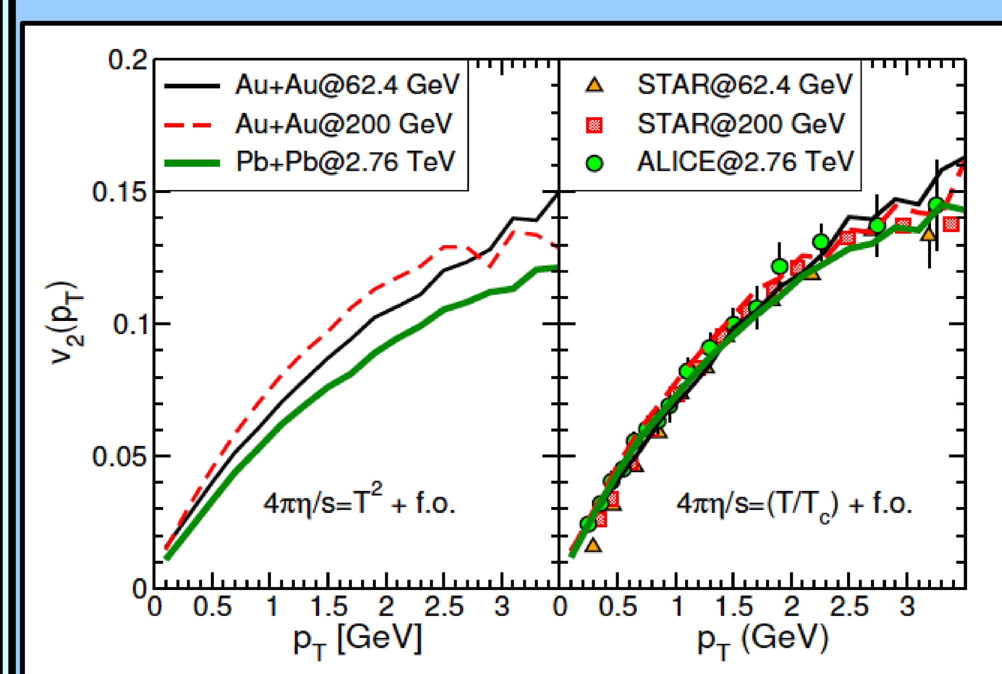
2- Temperature Dependent η/s(T)

S. Plumari, V. Greco, L.P. Csernai, arXiv:1304.6566 [nucl-th], Nuovo Cim. C037 (2014) 01, 68.





For 4πη/s=1 during all the evolution of the fireball we get a discrepancy for the $v_2(p_T)$, in particular we observe a smaller $v_2(p_T)$ at LHC. Notice only with RHIC → scaling for 4πη/s=1 and LHC data play a key role.



It is possible discriminate to have a discrimation for different η/s(T) in the QGP phase infact for η/s∝ T^2 → a discrepancy about 20%.

The scaling of $v_2(p_T)$ from Beam Energy Scan could suggest a particular 'U' shape of η/s(T), a behaviour typical of a phase transition.

Similar results: R.A. Lacey et al., PRL 112 (2014) 082302.

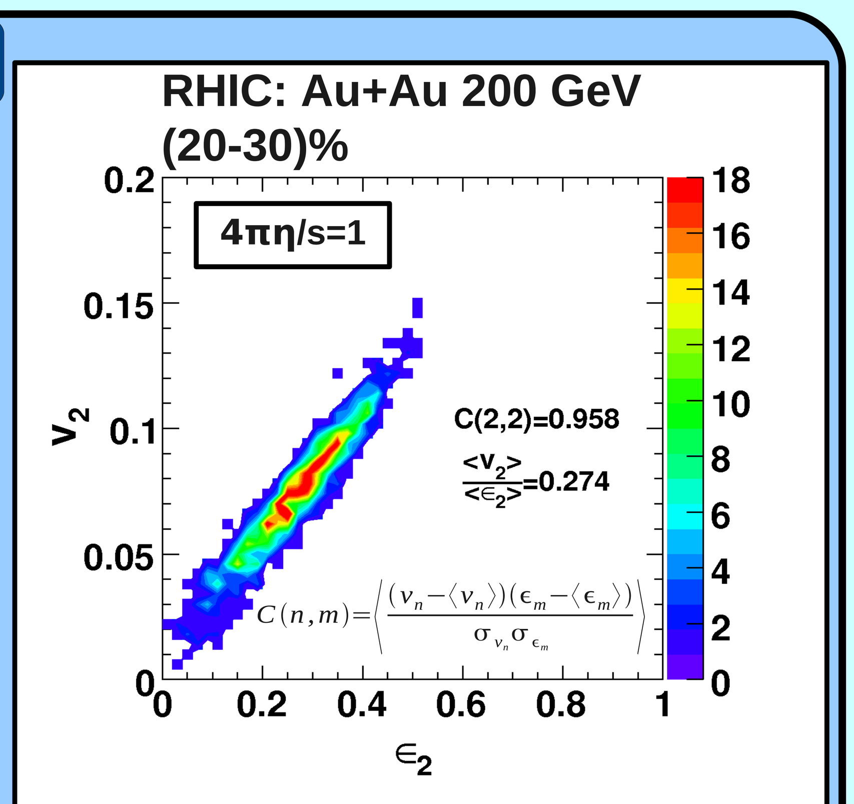
v_n, n>3 with an event-by-event analysis will put stronger constraint

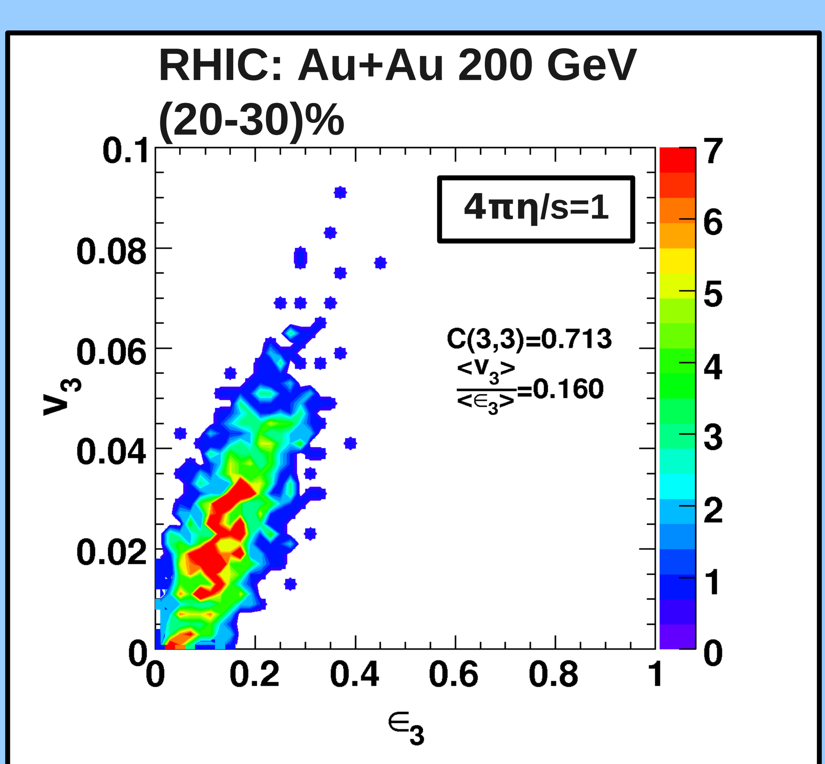
Implementation of local fluctuation under development.

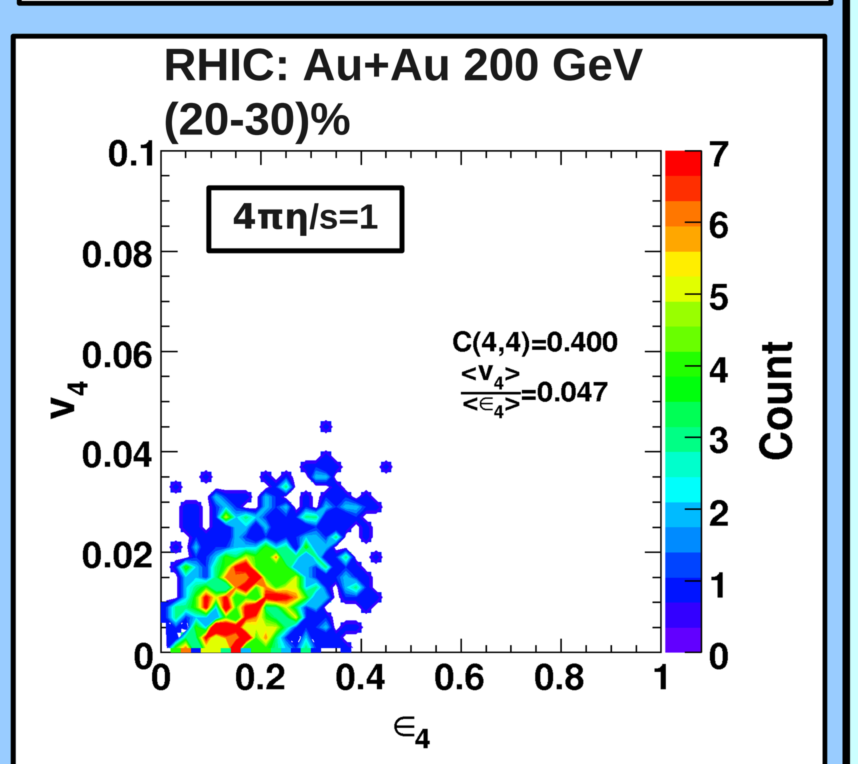
3- Initial State Fluctuations: v_n vs ε_n

- v_2 is strongly correlated to the corresponding initial ε_2.
- v_3 weakly correlated with ε_3.
- v_4 and ε_4 are uncorrelated, similar to viscous hydro calculations:

F.G. Gardim, F. Grassi, M. Luzum and J.Y. Ollitrault, Nucl. Phys. A 904 (2013) 503.
Niemi, Denicol, Holopainen and Huovinen Phys. Rev. C 87 (2013) 054901.

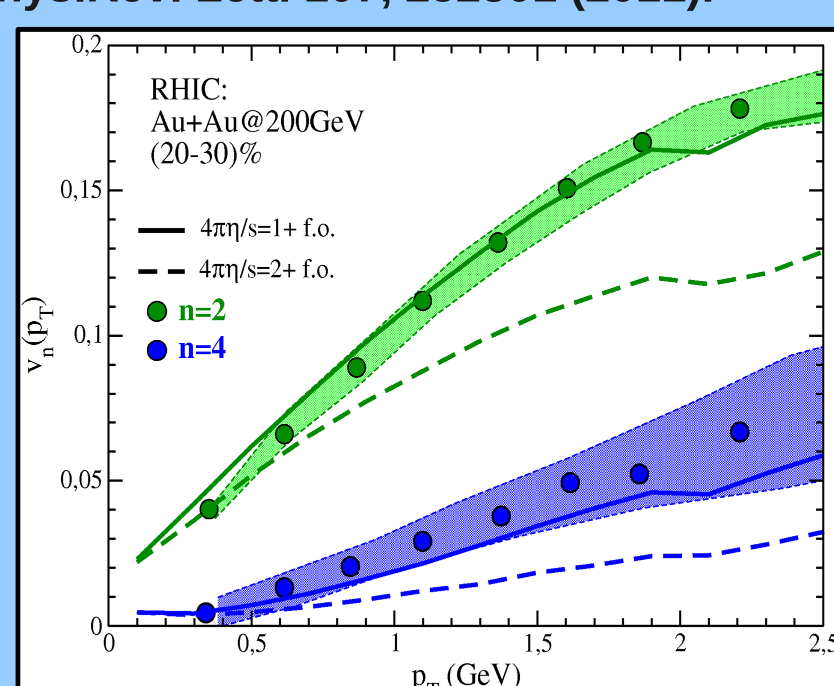


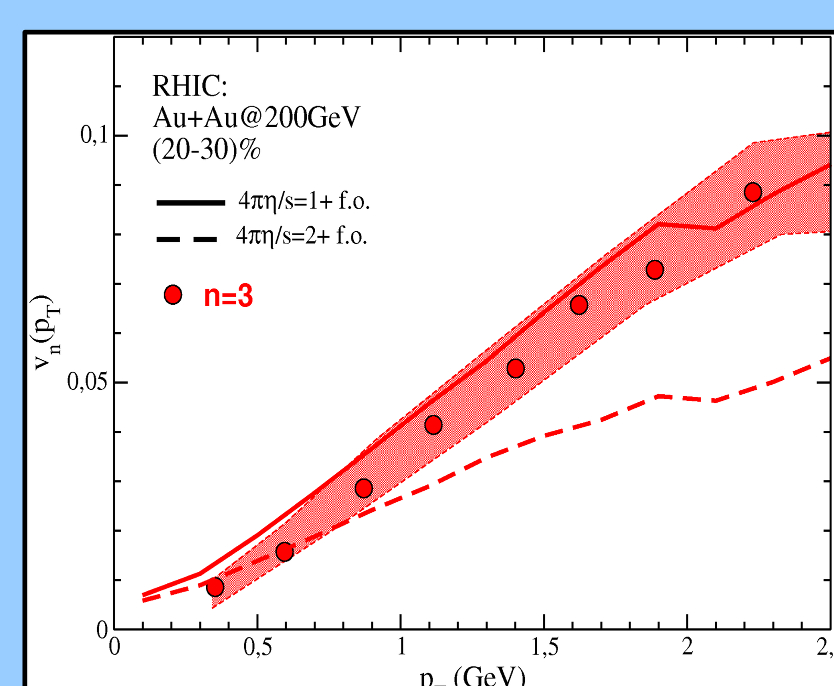




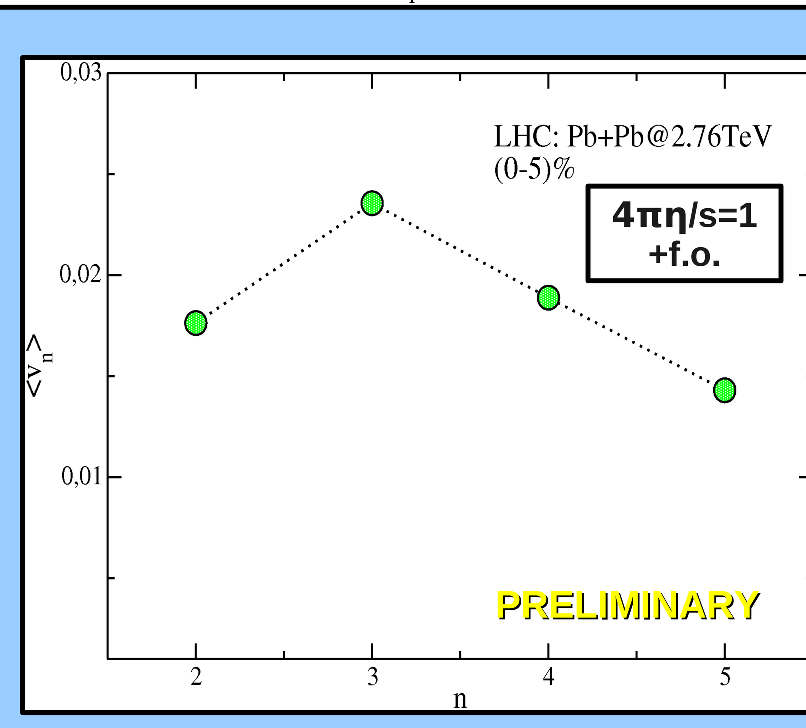
4- Initial State Fluctuations: $v_n(p_T)$

Data taken from: A. Adare et al. [PHENIX collaboration], Phys.Rev. Lett. 107, 252301 (2011).





Like in viscous hydro the data of $v_n(p_T)$ at RHIC energies can be described with 4πη/s=1 in the QGP phase.



5- Outlook

To study the role of η/s(T) on the $v_n(p_T)$ at different energies and the correlation between v_n and their initial ε_n.