Initial State fluctuations in ultra-central collisions in an event-by-event transport approach

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We discuss the generation of anisotropic flows v_n for a fluid at fixed η/s(T) by means of an event-by-event transport approach. Such an approach recovers the universal features of the ideal hydrodynamics. We discuss the effect of the η/s and its temperature dependence on the build up of the $v_n(p_T)$ revealing that only in ultra-central collisions (0−0.2%) the $v_n(p_T)$ have a stronger sensitivity to the T dependence of η/s in the QGP phase and this sensitivity increases with the order of the harmonic n. Moreover, the study of the correlations between the initial spatial anisotropies ϵ_n and the final flow coefficients vn shows that at LHC energies there is more correlation than at RHIC energies. The degree of correlation increases from peripheral to central collisions, but only in ultra-central collisions at LHC, we find that the linear correlation coefficent C(n,n)≈1 for n=2,...,5.

1 -Transport approach: viscous corrections

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

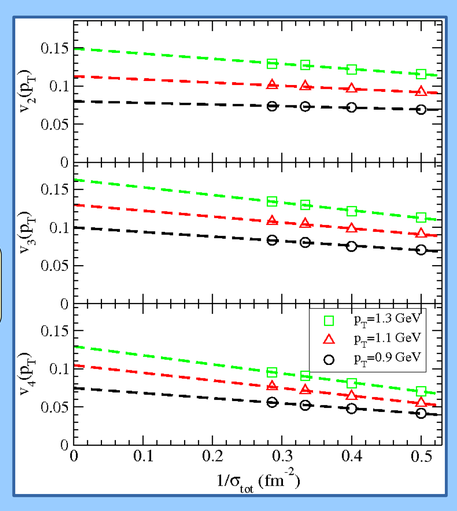
$$C_{22} = \frac{1}{2E_1}\int \frac{d^3p_2}{(2\pi)^3 2E_2}\frac{1}{\nu}\int \frac{d^3p'_1}{(2\pi)^3 2E'_1}\frac{d^3p'_2}{(2\pi)^3 2E'_2} f'_1 f'_2 \left|M_{1'2'\to 12}\right|^2 (2\pi)^4 \delta^{(4)}(p'_1+p'_2-p_1-p_2)$$

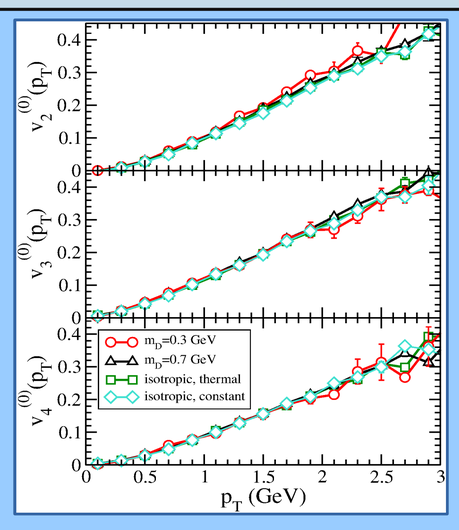
We evaluate viscous corrections to transverse momentum spectra and anisotropic flow by solving numerically a relativistic Boltzmann equation.

In the limit σ → ∞, a generic observable f(σ) can be expanded in powers of 1/σ.

$$f(\sigma) \underset{\sigma\to\infty}{\approx} f^{(0)} + \frac{1}{\sigma}\delta f + O\left(\frac{1}{\sigma^2}\right) \Rightarrow v_n(p_T) \underset{\sigma\to\infty}{\approx} v_n^{(0)}(p_T) + \frac{1}{\sigma}\delta v_n + O\left(\frac{1}{\sigma^2}\right)$$

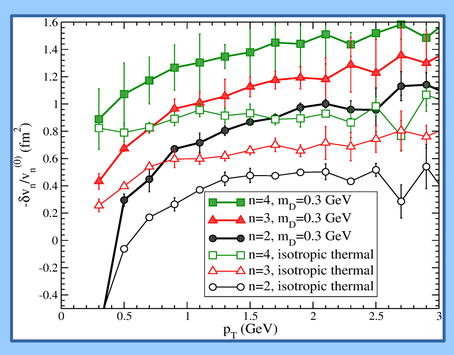
We evaluate the ideal hydrodynamics limit $f^{(0)}$, $v_n^{(0)}$ and the viscous corrections δf and δv_n solving the Relativistic Boltzmann eq. for large values of the cross section σ





In the limit σ → ∞ we find:

- If we keep fixed the initial $T^{\mu\nu}(x)$ the $v_n^{(0)}(p_T)$ don't depend on microscopical details and on initial conditions. Universal behavior of $v_n^{(0)}(p_T)$.
- $v_n^{(0)}(p_T)/\varepsilon_n$ is approximatively the same for all n and p_T



- In δv_n it is encoded the information about the microscopical details.
- Larger is n larger is the viscous correction to $v_n(p_T)$.
- Scaling: for p_T > 1.5 GeV → $-\delta v_n(p_T)/v_n^{(0)} \propto n$

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2 -Transport approach: fixing η/s(T)

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

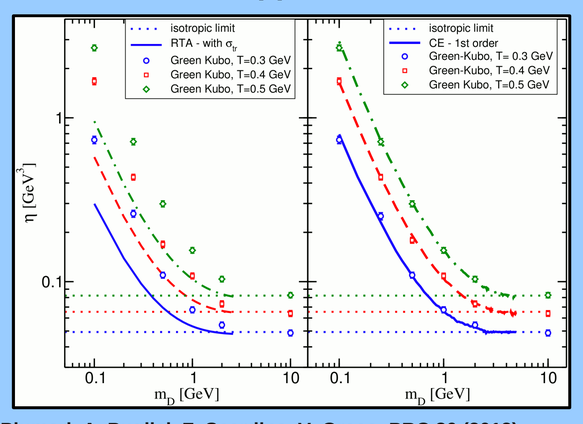
$$\frac{d\sigma}{dt} \sim \frac{\alpha_s^2}{(t-m_D^2)^2} \qquad \sigma_{tr} = \int d\Omega \sin^2(\theta_{cm})\frac{d\sigma}{d\Omega_{cm}} = \sigma_{tot} f(a) \leq \frac{2}{3}\sigma_{tot}$$

Chapman-Enskog approximation

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

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

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.
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Simulating a fixed η/s

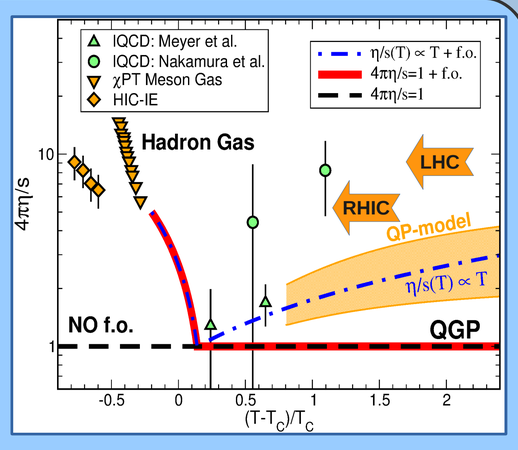
$$\eta(\vec{x},t)/s = \frac{1}{15}\langle p\rangle \tau_\eta \Rightarrow \sigma_{tot}^{\eta/s} = \frac{1}{15}\frac{\langle p\rangle}{g(m_D/2T)\,n}\frac{1}{\eta/s}$$

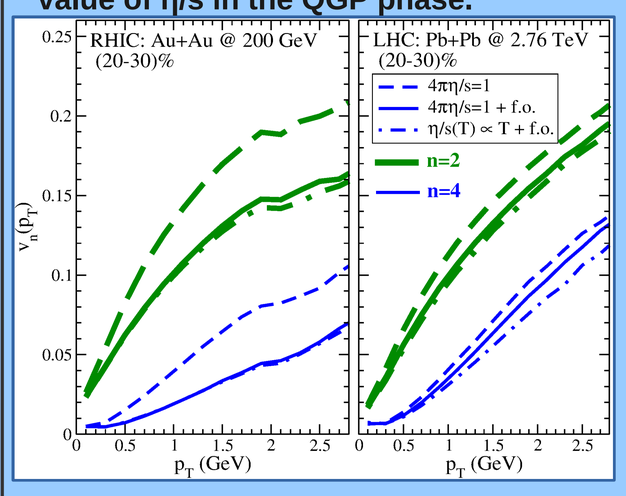
Instead of focusing on specific microscopic calculations we fixes the total cross section in order to have the wanted η/s.

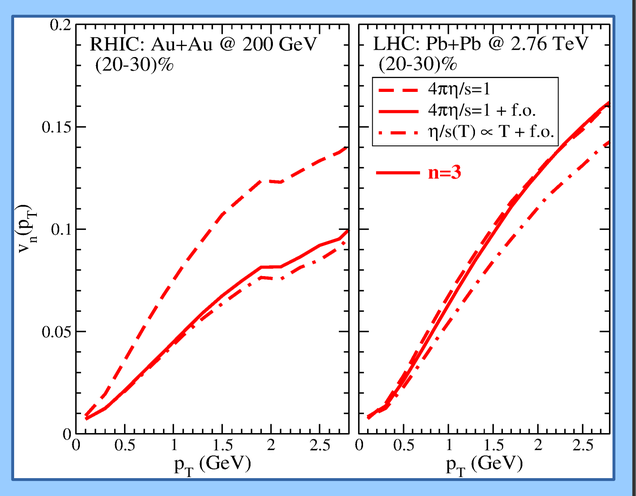
σ is evaluated in each cell of the coordinate space of our grid during the dynamics

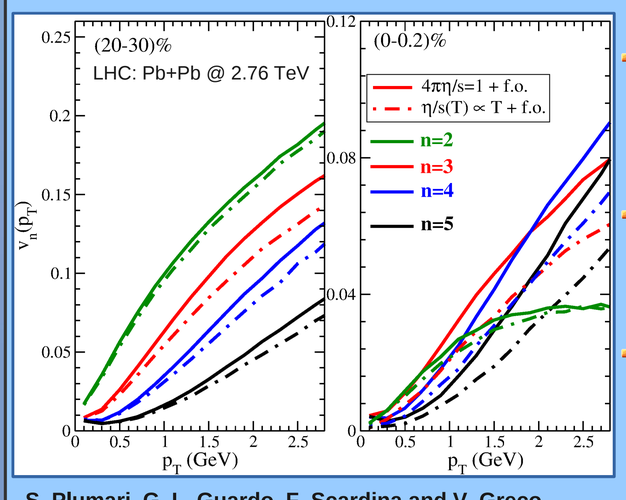
3 - Effects of η/s(T) on the $v_n(p_T)$

- Different v_n can probes different value of η/s(T) during the expansion of the fireball.
- $v_n(p_T)$ at RHIC is more sensitive to the value of the η/s at low temperature.
- $v_4(p_T)$ and $v_3(p_T)$ are more sensitive to the value of η/s than the $v_2(p_T)$.
- At LHC energies $v_n(p_T)$ is more sensitive to the value of η/s in the QGP phase.



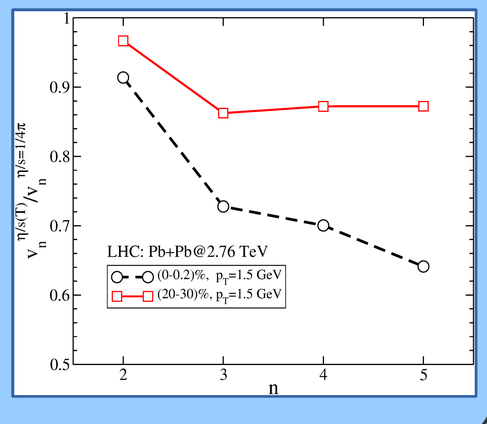






At LHC energies:

- At low p_T $v_n(p_T) \propto p_T^n$. At higher p_T v_2 saturates while v_n for n>3 increase linearly with p_T.
- In ultra-central collisions the $v_n(p_T)$ have a stronger sensitivity to the T dependence of η/s in the QGP phase.
- The sensitivity to the T dependence of η/s increases with the order of the harmonic n.



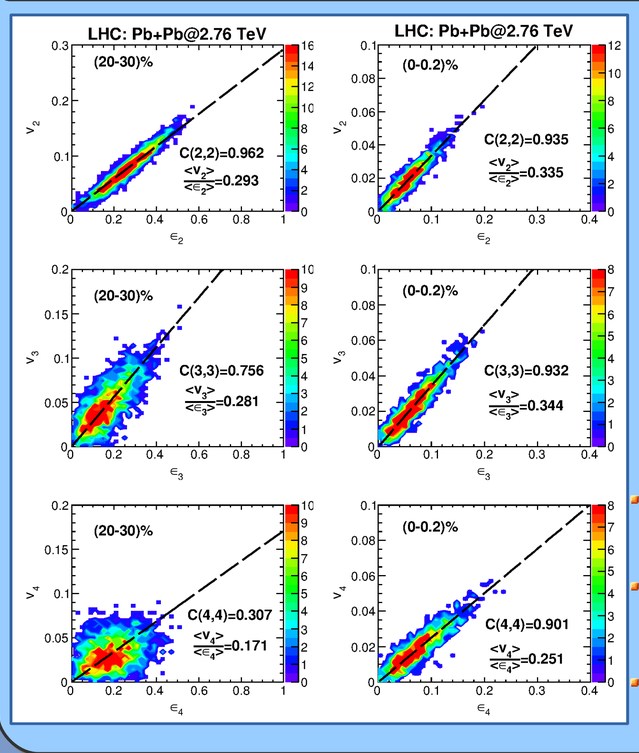
S. Plumari, G. L. Guardo, F. Scardina and V. Greco, arXiv:1507.05540 [hep-ph].

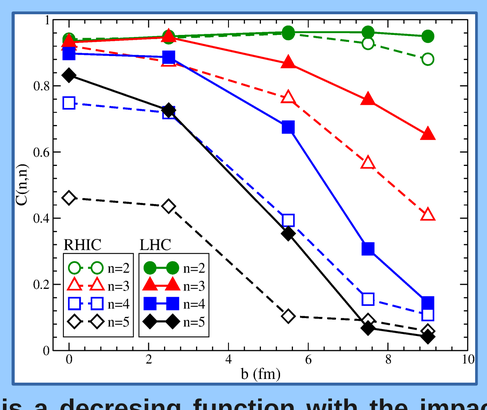
S. Plumari et al, J.Phys.Conf.Ser. 535 (2014) 012013.

4 - Correlations between v_n and ε_n

A measure of the linear correlation is given by the linear correlation coefficient:

$$C(n,m) = \left\langle \frac{(v_n - \langle v_n\rangle)(\epsilon_m - \langle \epsilon_m\rangle)}{\sigma_{v_n}\sigma_{\epsilon_m}} \right\rangle$$





- C(n,n) is a decresing function with the impact parameter.
- At LHC there is a stronger correlation between v_n and εn than at RHIC for all n.
- For ultra-central collisions v_n are strongly correlated to ε_n: C(n,n)=1 → $v_n \propto \varepsilon_n$ for n=2,3,4.

5 - Outlook

- To study the role of the Equation of State on the anisotropic flows $v_n(p_T)$ and on the viscous corrections δv_n.
- To include the hadronization by coalescence.