Bulk and Shear viscosity for small collisions systems at LHC energies in String Percolation Model

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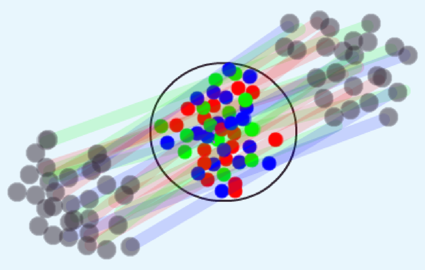
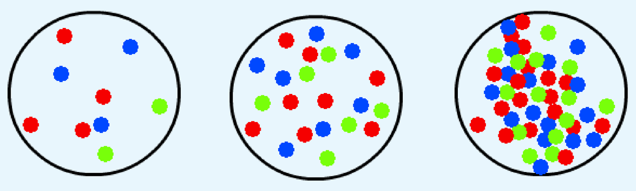
Abstract

We study the interplay of the contribution of bulk and shear viscosities in pp and pPb collisions at LHC energies in the framework of the String Percolation Model which exhibit a similar behavior as in the geometric phase transition given in heavy ion collision is showed for high multiplicities in small collision system. The results show that the bulk viscosity has a relevant contribution to the viscosity.

The Model



The model uses continuous two-dimensional percolation theory assuming that the color fields that are created at the time of a collision are strings, which project in the impact parameter plane forming disks. Within this same scheme two main parameters are defined. The first is related to the fraction of area occupied by the disks, the transverse impact parameter density of strings $\zeta^t = (S_0/S)\overline{N}^s$, which depends on the energy through $\overline{N}^s = 2 + 4\frac{S_0}{S}\left(\frac{\sqrt{s}}{m_p}\right)^{2\lambda}$.



The second relates $dN/d\eta$ for each energy with the definition of the average number of strings, and this function is called the color reduction factor $F(\zeta^t) \equiv \sqrt{(1-e^{-\zeta^t})/\zeta^t}$[1].

In order to know the corresponding values of ζ^t and $F(\zeta^t)$ we use the transverse momentum distribution power law

$$\frac{1}{N}\frac{d^2N_{ch}}{d\eta dp_T}\bigg|_{\eta=0} = a\frac{(p_0 b)^{\alpha-2}}{(p_T + p_0 b)^{\alpha-1}}. \tag{1}$$

In the thermodynamic limit $b \to \sqrt{F(\zeta_0)/F(\zeta)}$, the deviation between high multiplicity (ζ) and minimum bias events (ζ_0).

To obtain a, p_0 and α we make a fit over the minimum bias transverse momentum distributions data[2,3] as seen in Figure 1.

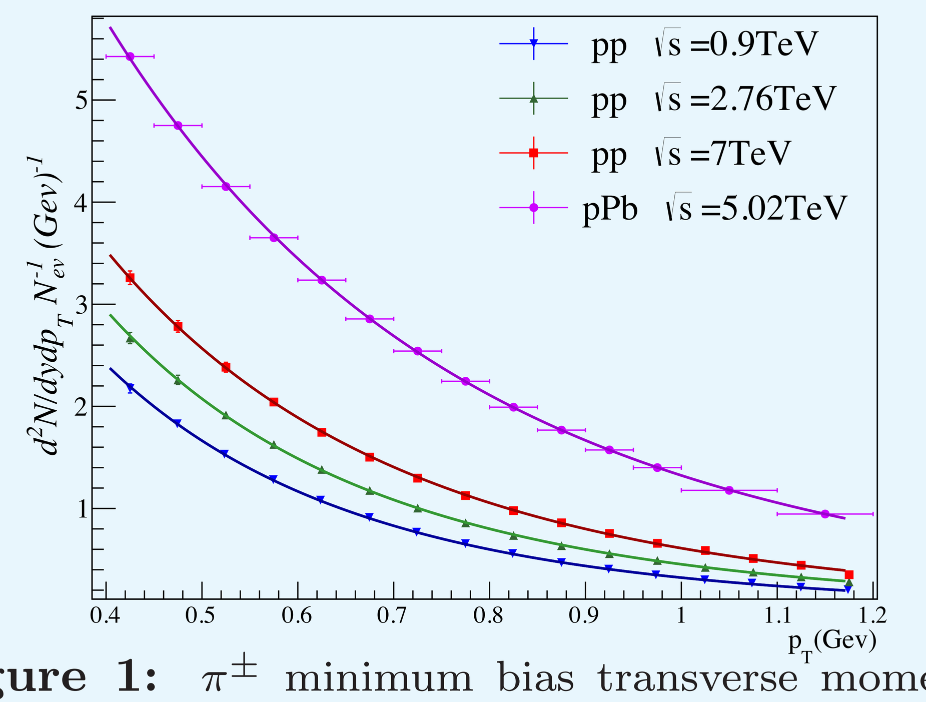


Figure 1: $\pi^{\pm}$ minimum bias transverse momentum distributions of pp & pPb collisions.

$\sqrt{s}$	a	p_0	α
5.02	29.63±6.76	3.35±0.91	10.83±2.20
7	33.48±9.3	2.32±0.88	9.78±2.53
2.76	22.48±4.2	1.54±0.46	7.94±1.41
0.9	23.29±4.48	1.82±0.54	9.4±1.8

Table 1: Energy parameters obtained.

Then we used $b \neq 1$ to fit over each multiplicity, thus obtaining the values of $F(\zeta)$ shown in Figure 2.

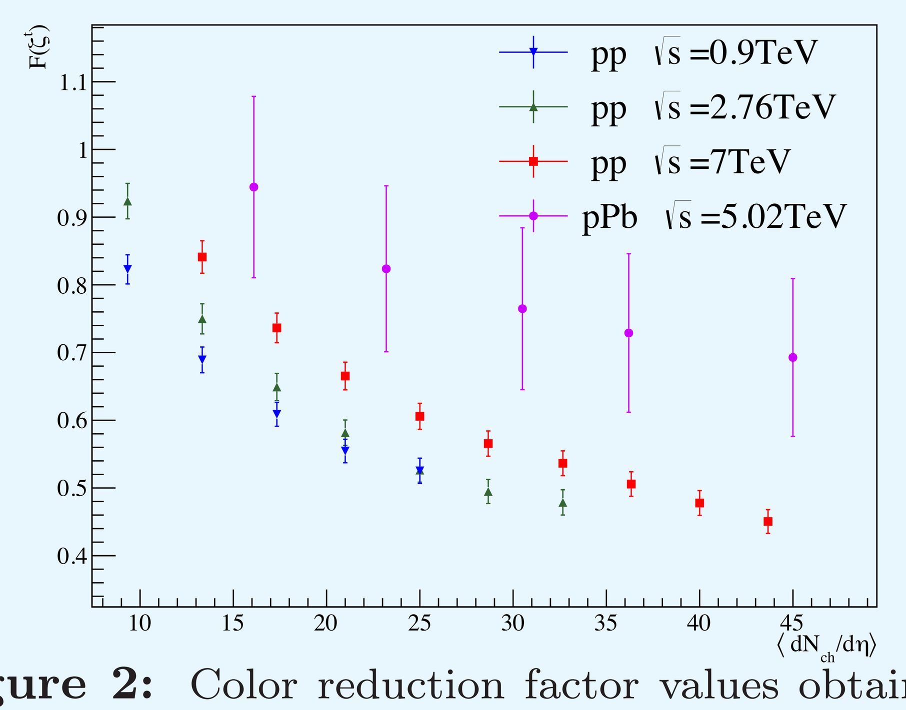


Figure 2: Color reduction factor values obtained for each energy and multiplicity.

Viscosity determination

The effective system temperature is obtained, since the average tension of the string fluctuates due to the no constant chromodynamic field, $\langle x^2\rangle = \pi\langle p_T^2\rangle_1/F(\zeta^t)$. A non-Gaussian distribution of the tension fluctuations of these strings gives a thermal distribution $T(\zeta^t) = \sqrt{\langle p_T^2\rangle_1/2F(\zeta^t)}$[4], considering $\langle p_T\rangle_1 = 190.25 \pm 11.2$ MeV and $T_c = 154 \pm 9$ MeV[1,4]. In terms of the effective temperature obtained we study the ratio given by the relativistic kinetic theory $\eta/s \simeq T\lambda_{fp}/5$ with $\lambda_{fp} \sim 1/n\sigma_{tr}$ the mean free path, $n = N_{\text{sources}}/S_N L$ the density of effective sources per unit volume and $\sigma_{tr} = S_N(1-e^{-\zeta^t})/N_{sources}$ the transverse area of an effective string, obtaining

$$\frac{\eta}{s} = \frac{TL}{5(1-e^{-\zeta^t})}. \tag{2}$$

The bulk viscosity characterizes the internal properties of the fluid, the microscopic formula of the bulk viscosity ζ over the corresponding relaxation time τ_Π of causal dissipative relativistic fluiddynamics are obtained at finite temperature and chemical potential by using the projection operator method[6]

$$\frac{\zeta}{\tau_\Pi} = \left(\frac{1}{3} - c_s^2\right)(\varepsilon + P) - \frac{2}{9}(\varepsilon - 3P), \tag{3}$$

with the sound velocity $c_s^2 = \left(\frac{\zeta^t e^{-\zeta^t}}{1-e^{-\zeta^t}} - 1\right)\left(\frac{0.019\Delta}{3(1-e^{-\zeta^t})} - 0.33\right)$, where we have assume that the trace anomaly Δ can be estimated by the inverse of the η/s ratio[1]. The pressure is obtained from the thermodynamic definition of the trace anomalous $P = \frac{1}{3}\left(\varepsilon - T^4 s/\eta\right)$ and ε is the Bjorken energy density in approximation for a gas $\varepsilon = \frac{3N_p\langle E\rangle}{2\tau S}\frac{dN}{d\eta}$, were$\langle E\rangle = 400$MeV is the average energy per particle[7].

Results

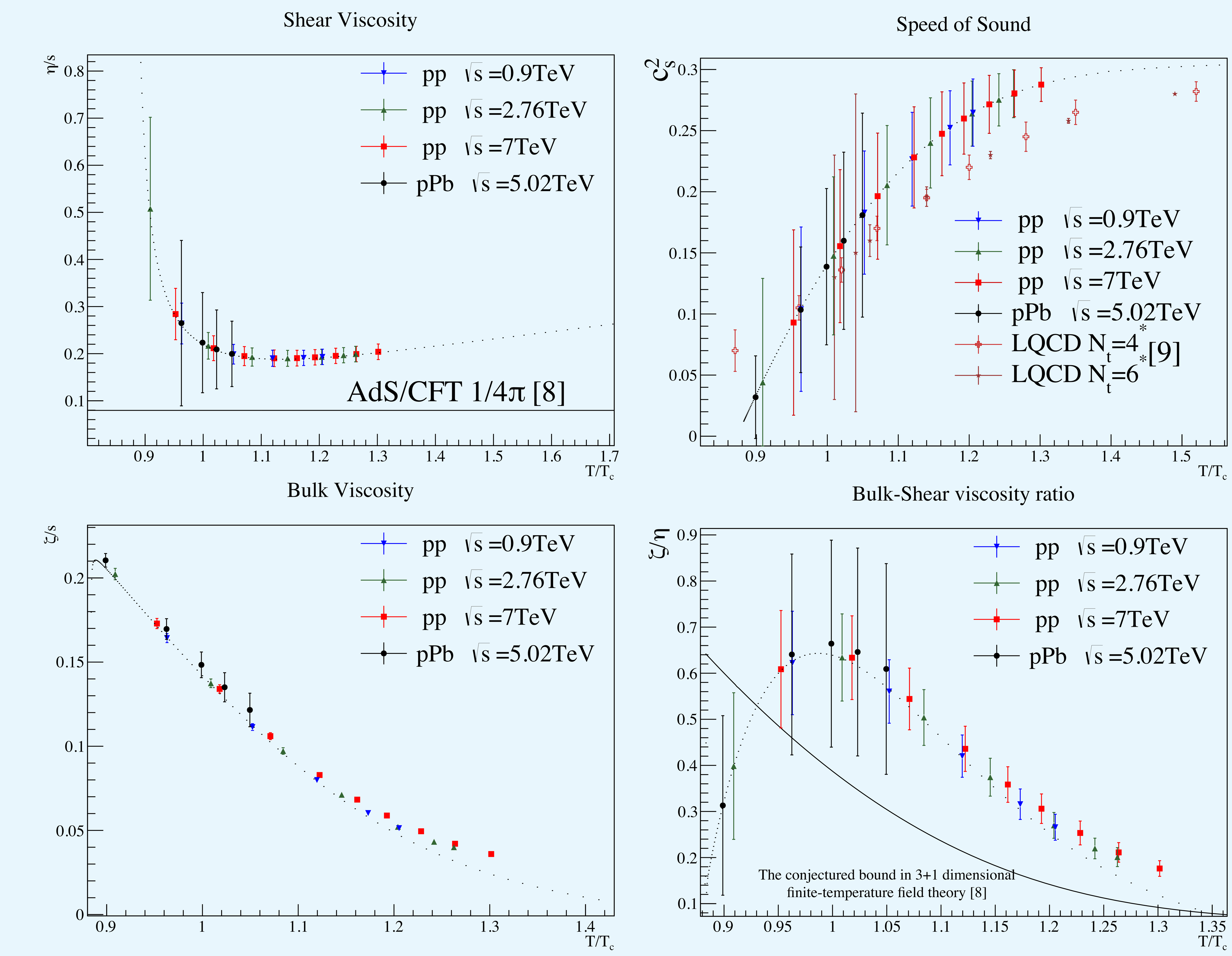


Figure 3: Results corresponding to the velocity of sound and the shear and bulk viscosities. In addition to the comparison between these two viscosities whit $\frac{\zeta}{\eta} = 2\left(\frac{1}{3} - c_s^2\right)$.

Conclusions

The behavior of the velocity of the sound goes according to the results obtained in Lattice[9]. The value of shear viscosity for high multiplicities are comparable to those obtained in nuclear collisions which indicates we are close to the geometric phase transition. The values of the bulk viscosity are comparable with the shear viscosity, and the ratio between them show a quite significant behavior in the region of critical temperature, which indicates that the bulk viscosity and internal fluctuations play a role on the system flow, and it suggests that there is a change of phase even in small systems.

References

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