# Collective medium in small collision systems with percolation color sources

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## Abstract

- We analyze high multiplicity proton-proton ($p-p$) collision data in the framework of the String Percolation Model (SPM) that has been successful in describing several phenomena of multiparticle production, including the signatures of recent discovery of strongly interacting partonic matter, the Quark Gluon Plasma (QGP), in relativistic heavy-ion collisions. The study shows predicted signature of change of phase, and results for 13 TeV ($p-p$) collisions.

## Motivation and Introduction

- Recent results at the Large Hadron Collider (LHC) at CERN had shown an unexpected feature, namely the "ridge" in the long range near side angular correlation, in distinct class of "high multiplicity" events of proton-proton collisions [1-2] at $\sqrt{s}=7$ TeV at LHC has revived the idea [3-6] of the possible formation of a collective medium in $pp$ collisions.

## SPM Model

In the SPM, the sources of multiparticle productions are the color strings between the colliding partons.The transverse impact parameter density of strings, $\zeta^t$.In pp $\zeta^t \equiv (\frac{r_0}{R_p})^2\bar{N}^s$ where $r_0$ is $\simeq$ **0.25** fm the single string transverse size, $R_p \simeq$ **1** fm is the proton transverse size and $\bar{N}^s$ is the average number of single strings. $\zeta_c^t \simeq$ **1.2−1.5** ( depending on the profile function homogeneous or Wood Saxon type).$dN/dy$ and the number ($\overline{N}^s$) of strings as: $\frac{dN}{dy} = \kappa F(\zeta^t)\bar{N}^s$, where $\kappa$ is a normalization factor $\sim$ **.63** [7,8] and $F(\zeta^t) \equiv \sqrt{\frac{1-e^{-\zeta^t}}{\zeta^t}}$ slows down the rate of increase in particle density with energy and with the number of strings. $N_p^s = 2 + 4(\frac{r_0}{R})^2(\frac{\sqrt{s}}{m_p})^{2\lambda}$ with $m_p$ the mass of the proton and $\lambda$ a constant parameter $\simeq$ **.201** [7,8].

## High Multiplicity events

SPM had given a qualitative description of the centre-of-mass energy dependence of mid-rapidity multiplicity and the pseudorapidity distributions [2] of produced charged particles in $pp$ collisions, for the entire range of energy, available so far. Now we use $d\langle N_{ch}\rangle/d\eta$ - dependent identified particle spectra from $pp$ collisions at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV [2], to determine $\zeta$, we use the invariant transverse momentum spectra given by a power law:

$$\frac{1}{N}\frac{d^2N}{dp_T^2} = \frac{(\alpha-1)(\alpha-2)}{2\pi p_0^2}\frac{p_0^\alpha}{[p_0+p_T]^\alpha} \quad (1)$$

($p_0$ and $\alpha$ - energy dependent parameters). The total multiplicity is obtained by the mean over all the clusters configurations $\mu = \left\langle \sum_{i=1}^M \sqrt{\frac{n_i S_i}{S_1}}\right\rangle \mu_1$ where $M$ is the total number of clusters in a event and $n_i$ the number of strings that form the $i$ cluster. Considering only the clusters which contributes to the central region the general formula, we can describe the general equation that relates the high multiplicity (with string density $\zeta_{HM}$) and min bias distributions as:

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

with $a = \frac{\left\langle \sum_{i=1}^M \sqrt{\frac{nS_i}{S_1}}\right\rangle}{\left\langle \sum_{i=1}^M \sqrt{\frac{nS_i}{S_1}}\right\rangle_{pp}}\frac{dN}{d\eta}|^{pp}_{\eta=0}\frac{(\alpha-2)}{2\pi}$ and $b = \sqrt{\left\langle \frac{N}{\sum_{i=1}^M\sqrt{\frac{nS_i}{S_1}}}\right\rangle / \left\langle \frac{N}{\sum_{i=1}^M\sqrt{\frac{n_iS_i}{S_1}}}\right\rangle_{pp}}$, by applying the thermodynamic limit with a vectorial color sum $b \rightarrow \sqrt{F(\zeta)/F(\zeta_{HM})}$.

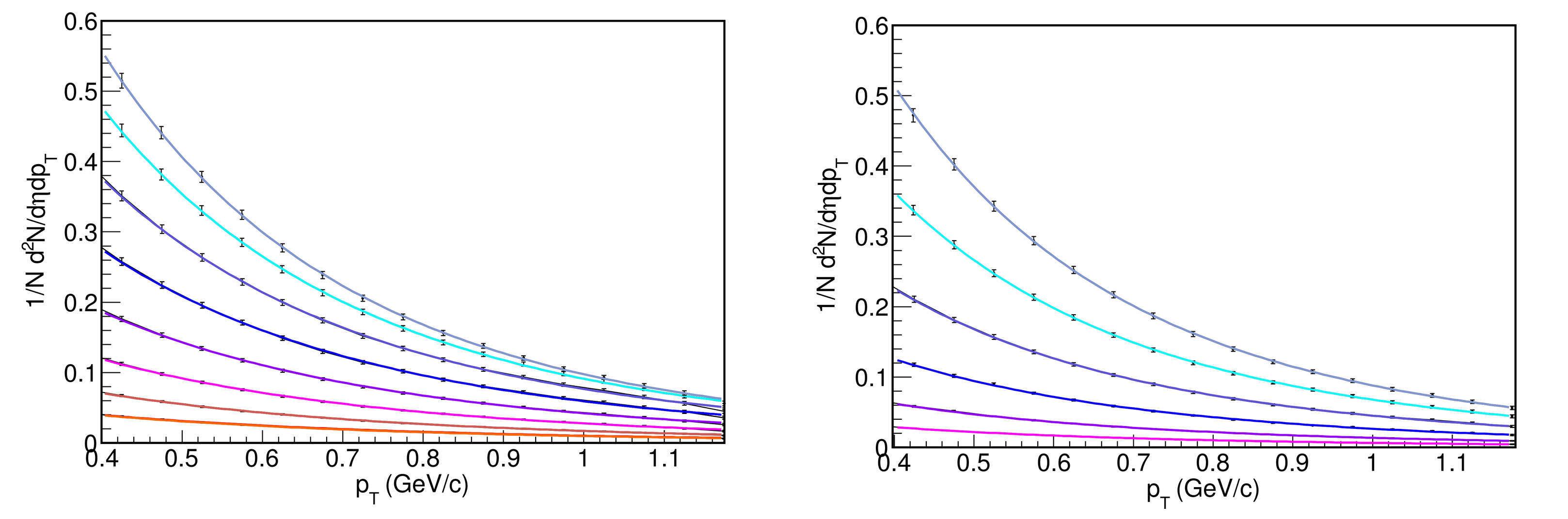


Fig. 1 Fits to the transverse momentum distribution for energies $\sqrt{s}$ = 7 TeV in $p-p$ collisions for different multiplicity classes from $N_{track}$ = **131** grey line to $N_{track}$ = **40** orange line. Data taken from reference [2]. The fit is restricted to $p_T >$ .**4** GeV/c to avoid the effect of resonance decays.

To obtain $a$, $p_0$, $\alpha$ we perform a fit to the transverse momentum distributions of charged particles from minimum bias $pp$ events at the energies $\sqrt{s}$ = **900** GeV, 2.76 TeV, 7 TeV [2] with equation (2)

## High multiplicity variable dependences

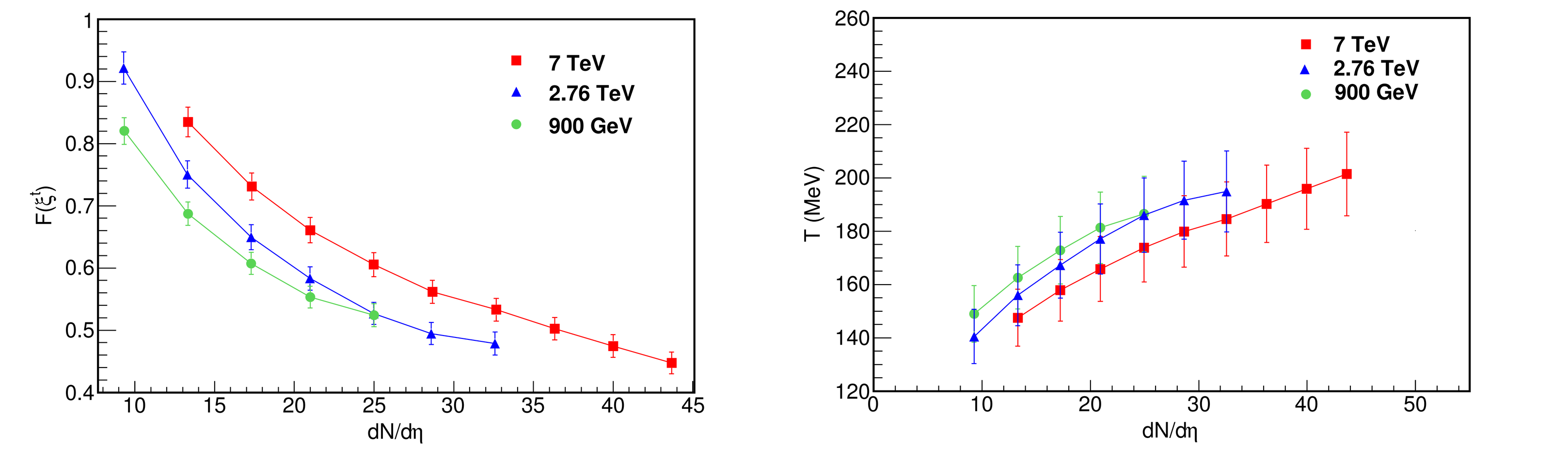


Fig. 2 Left side color reduction factor at high multiplicities for different energies, right side effective temperature vs $dn/d\eta$

- The Schwinger mechanism for massless particles is given by the expression $\frac{dN}{dp_T} \sim e^{-\sqrt{2F(\zeta^t)}\frac{p_T}{\langle p_T\rangle_1}}$, which can be related to the average value of the string tension $\langle x^2\rangle = \pi\langle p_T^2\rangle_1/F(\zeta)$ [10], this value fluctuates around its mean value because the chromoelectric field is not constant, the fluctuations of the chromo electric field strength lead to a Gaussian distribution of the string tension that transform it into a thermal distribution, where the temperature is given by the relation $T(\zeta^t) = \sqrt{\frac{\langle p_T^2\rangle_1}{2F(\zeta^t)}}$
- We consider that the experimentally determined chemical freeze out temperature is a good measure of the phase transition temperature $T_c$. We calculate the effective temperature, $T$, from the equation, for each multiplicity class for a critical density $\zeta_c = 1.2$ and at the critical temperature $T_c = 154 \pm 9$ MeV, as obtained by the latest LQCD results from the HotLQCD collaboration, with the corresponding $\langle p_T\rangle_1 \sim 190.25 \pm 11.12$ MeV/c consistent with the measured of direct photon enhanced measured.

## Change of phase indication

- In the relativistic kinetic theory as $\eta/s \simeq \frac{T\lambda_{fp}}{5}$ where $\lambda_{mfp}$ is the mean free path $\sim \frac{1}{n\sigma_{tr}}$, n is the density of the effective number of sources per unit volume and $\sigma_{tr}$ is the transport cross section, $n = \frac{N_{sources}}{S_N L}$.
- It is considered that $\frac{N_{sources}}{S_N L}\sigma_{tr} = (1-e^{-\zeta^t})/L$ considering $L = 1fm$ the longitudinal extension of the source one can give the relation $\eta/s$ in terms of $\zeta^t$ [10], as: $\frac{\eta}{s} = \frac{TL}{5(1-e^{-\zeta^t})}$

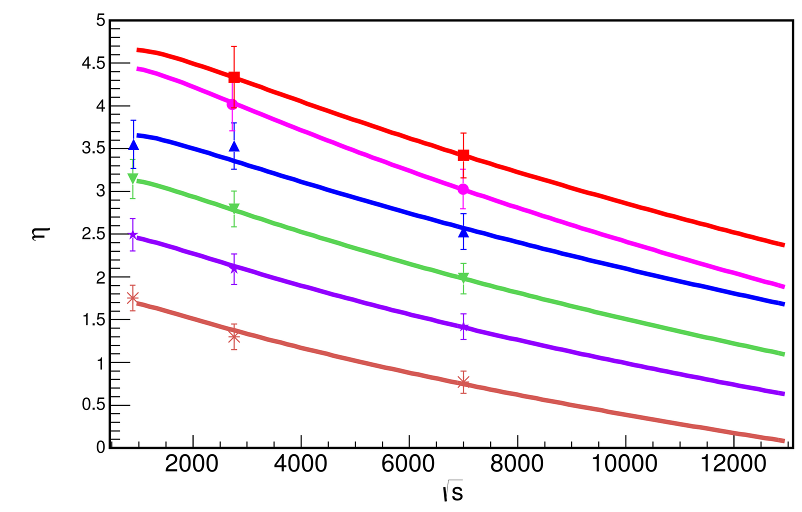


Fig 3. Extrapolation of $\zeta_{HM}$ for different multiplicity classes higher in red to lower in brown.

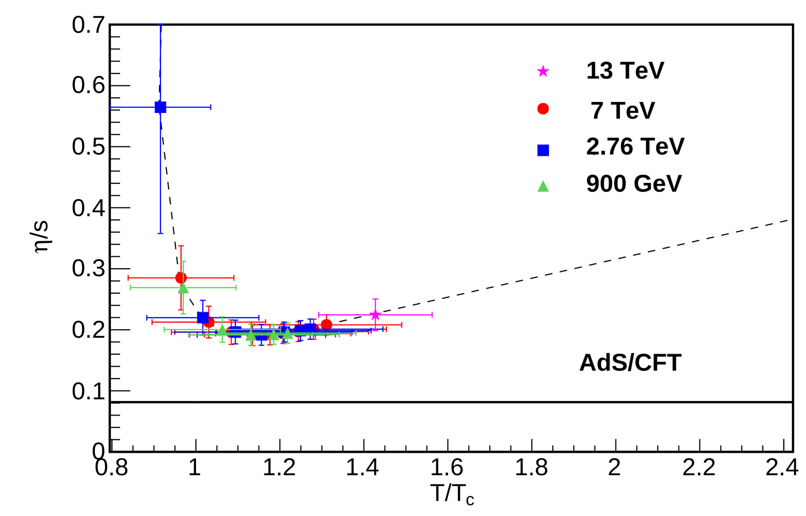


Fig. 4 Shear viscosity over entropy ratio for 7 TeV high multiplicity classes $p-p$ collisions corresponding to $N_{track}$ = **40** to $N_{track}$ = **131**, with the $T_c$ = **154** ± **9** MeV. In here we have plot the corresponding value corresponding to an approximate number of tracks ∼ **155** ± **7** corresponding to high multiplicity event in 13 TeV.

## Conclusions

The model gives a clear indication of the geometrical phase transition for measured high multiplicity $p-p$ events, that may provide a explanation to the observed unexpected feature of the $p-p$ collision data at LHC energies.
*See Reference [11].

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