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Rapidity dependence of particle densities in pp and AA collisions in the string percolation approach

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Abstract. We use multiple scattering and energy conservation arguments to describe $dn/dn_{N_A N_A}$ as a function of dn/dn_{pp} in the framework of string percolation.

As nuclei are made up of nucleons it is natural to look at nucleus-nucleus (A-A) collisions as resulting from the superposition of nucleon-nucleon (p-p) collisions, in the spirit of Glauber model approach. In the single scattering limit the average number of participating nucleons per nucleus, N_A behave incoherently and the multiplicity at low energy corresponds to the wounded nucleon model [1][2][3].

$$\frac{dn}{dy}|_{N_A N_A} = \frac{dn}{dy}|_{pp} N_A \tag{1}$$

The equation (1) does not agree in general with data. At higher energies one has to take into account multiple scattering to obtain

$$\frac{dn}{dy}|_{N_A N_A} = \frac{dn}{dy}|_{pp} (N_A^{1+\alpha(s)} - N_A) \tag{2}$$

where $N_A^{1+\alpha(s)}$ is the estimated total number of nucleon-nucleon collisions and single scattering was subtracted [4]. It can be noticed that the energy momentum conservation constrains the combinatorial factors of the Glauber calculus at low energy. We address the problem of the energy momentum of the N_A valence strings shared by $N_A^{4/3}$ mostly sea strings, by reducing the effective number of sea strings rather than reducing the sea plateau. We write [4][5]

$$N_A^{4/3} \rightarrow N_A^{(1+\alpha(s))} \tag{3}$$

with $\alpha(s) = \frac{1}{3}(1 - \frac{1}{1+\ln(\sqrt{s/s_0}+1)})$, such that for $\sqrt{s} << \sqrt{s_0}$, $\alpha(\sqrt{s}) \rightarrow 0$, we are back to the wounded nucleon model, and for $\sqrt{s} >> \sqrt{s_0}$, $\alpha(\sqrt{s}) \rightarrow \frac{1}{3}$, we have fully developed Glauber calculus.

Here as in [2] [3] our framework is the Dual Parton Model with parton saturation, and we work with Schwinger strings, with fusion and percolation [6]. In this framework the interactions in $N_A N_A$ collisions occur with the formation of longitudinal color strings in rapidity, stretched between the partons of the projectile and the target. In the impact parameter plane due to the confinement, the color of strings is confined to small area in transverse space $S_1 = \pi r_0^2$ with $r_0 \sim .2 - .3$ fm, these strings decay into new ones by $q\bar{q} - \bar{q}q$ pair production and subsequently hadronize to produce the observed hadrons.

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In the impact parameter plane the strings appear as disks and as energy-density increases the discs overlap, fuse and percolate, leading to the reduction of the overall color [7][8][9]. A cluster of n strings behaves as a single string with energy momentum corresponding to the sum of the individual ones. An essential quantity is the color reduction factor $F(\eta^t_{N_A}) = \sqrt{\frac{1-e^{-\eta^t_{N_A}}}{\eta^t_{N_A}}}$. The particle density dn/dy is expected to be proportional to the average number of strings $N^s_{N_A}$ (see [4]),

$$\frac{dn}{dy}|_{N_A N_A} \sim \bar{N}^s_{N_A}. \tag{4}$$

Considering $\bar{N}^s_{N_A} = N^s_p N_A^{1+\alpha}$ where N^s_p is the number of proton strings, at low energy N^s_p is around 2 growing with energy as $e^{2\lambda Y}$ (faster than $\frac{dn}{dy}|_{pp}$) so that we can approximately write $N^s_p = 2+4(\frac{r_0}{R_p})^2 e^{2\lambda Y}$. Instead of (4) we have now

$$\frac{dn}{dy}|_{N_A N_A} \sim F(\eta^t_{N_A})\bar{N}^s_{N_A}, \tag{5}$$

where $F(\eta^t_{N_A})$ is a tool to slow down the increase of dn/dy with energy and number of participating nucleons. This reduction is due to the fact that the strength of the color field inside a cluster of n strings instead of being n times the strength of the color field of a single string is $\sqrt{n}$ due to the random direction of the individual color field in color space. We have considered S_{N_A} as the interaction area of the overlap region projected in the impact parameter plane, covered by N_A nucleons from nucleus A. Using $S_{N_A} = \pi R_p^2 A^{2/3}(N_A/A)^{5/3}$, where R_p is the proton radius [4], the result gives at $\eta = 0$,

$$\frac{1}{N_A}\frac{dn}{dy}|_{N_A N_A} = \kappa\frac{dn}{dy}|_{pp}[1 + \frac{F(\eta^t_{N_A})}{F(\eta^t_p)}(N_A^{\alpha(\sqrt{s})} - 1)], \tag{6}$$

with κ being a normalization factor, $\eta^t_{N_A} = \eta^t_p N_A^\alpha(\frac{A}{N_A^{2/3}})$.

We now generalize the results obtained in reference [4]. Based on the good description on data obtained by using the formula (6) for different atomic number and number of participants for different energies at mid rapidity, by applying the same formalism as used in pp to describe the rapidity evolution as suggested in references [10][11][12], we obtain a general formula for pseudo-rapidity dependence of AA collisions:

$$\frac{1}{N_A}\frac{dn^{N_A N_A}_{\text{ch}}}{d\eta}\bigg|_\eta = \kappa' J\, F(\eta^t_p)\, N^s_p \frac{\left(1 + \frac{F(\eta^t_{N_A})}{F(\eta^t_p)}(N_A^{\alpha(\sqrt{s})} - 1)\right)}{\exp\left(\frac{\eta-(1-\alpha)Y}{\delta}\right) + 1} \tag{7}$$

where J is the usual Jacobean $J = \frac{cosh\eta}{\sqrt{k_1 + sinh^2\eta}}$ and $\kappa' = \frac{\kappa}{J(\eta=0)}(\exp(\frac{-(1-\alpha)Y}{\delta}) + 1)$. We now apply the formula to describe the charge multiplicity in p-p collisions for different energies in pseudo rapidity, from our general formula (7) by using $N_A = 1$ and $A = 1$, to consider p-p collisions, the expression is reduced to

$$\frac{dn^{pp}_{\text{ch}}}{d\eta}\bigg|_\eta = \kappa'\, F(\eta^t_p)\, N^s_p \frac{1}{\exp\left(\frac{\eta-(1-\alpha)Y}{\delta}\right) + 1}. \tag{8}$$

Note that the pseudorapidity dependence for pp and AA collisions, it is described by the factor, $\frac{1}{(\exp(\frac{\eta-(1-\alpha)Y}{\delta})+1)}$, with α and δ being constant parameters. This dependence was obtained in [11][12], giving rise to an increase with energy smaller at central pseudorapidity $\eta = 0$ than at large pseudorapidity $\eta = Y$.

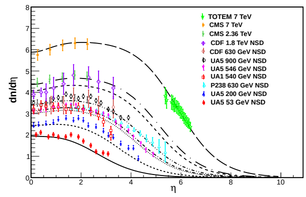

Figure 1. Comparison of the results from the evolution of the $dn_{ch}/d\eta$ with dependence in pseudorapidity from equation (8) for p-p collisions at different energies (lines), data is taken from ref. [13] [14] [15].

In figure 1 the comparison of the formula (8) shows a good agreement on the evolution in pseudo rapidity with an increase of the $dn_{ch}/d\eta$ in the plateau region as the energy increases.

In figures 2, and 3 it is shown the comparison between our results from formula (7) with data. In the right side of figure 3, we show some predictions for 3.2, 3.9 and 5.5 TeV energies at centrality $0-5\%$, for Pb-Pb collisions.

In the above computations we have used the following values of the parameters: $\kappa = 0.63 \pm 0.01$, $\lambda = 0.201 \pm 0.003$, and $\sqrt{s_0} = 245 \pm 29$ GeV, as were obtained in [4].

We had fixed the values of the parameters $\alpha \simeq 0.34$, $\delta \simeq 0.84$, $k_1 = 1.2$ to adjust the equation (7) with pp collisions data [13-15], with the same aim as in reference [12], and to extend the description of the pseudorapidity evolution to AA collisions [5]. As a result we have found that we are able to describe the rise with energy in AA and pp collisions with the same power- like exponent and rapidity evolution, due to the energy conservation effects which give rise to an additional energy dependence vanishing at extremely high energies.

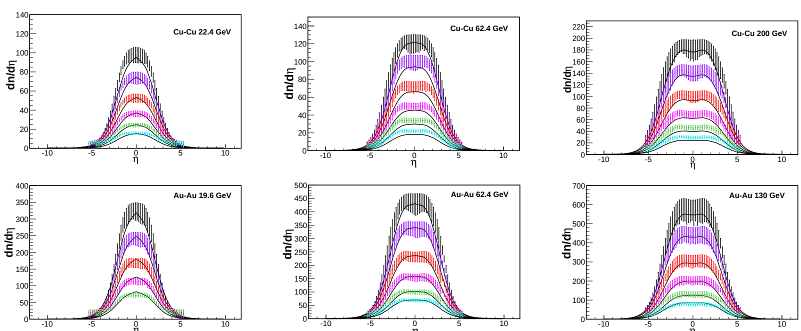

Figure 2. Comparison of the results from equation (7). Bottom of the figure shows Cu-Cu collisions at 22.4 GeV, 62.4 GeV, and 200 GeV energies, data is taken from ref. [16], Below is shown Au-Au collisions at 19.6 GeV, 62.4 GeV and 130 GeV energies, data is taken from [17]. Error bars in color blue, green, pink, red, purple and black are used for the corresponding centralities $45-55\%$, $35-45\%$, $25-35\%$, $15-25\%$, $6-15\%$, $0-6\%$ respectively, lines in black show our results.

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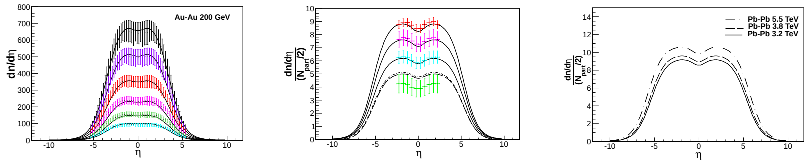

Figure 3. Comparison of the results from the evolution of the $dn_{ch}/d\eta$ in pseudorapidity from equation (7). Left side Au-Au collisions at 200 GeV, data is taken from [17], center Pb-Pb collisions at 2.76 TeV, data is taken from [18]. Error bars in color blue, green, pink, red, purple and black are used for the corresponding centralities 45 – 55%, 35 – 45%, 25 – 35%, 15 – 25%, 6 – 15%, 0 – 6% respectively, lines in black are the model results. Right side show predictions for Pb-Pb collisions at 3.2, 3.9 and 5.5 TeV energies at 0 – 5% centrality.

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