Rapidity dependence of particle densities in pp-AA collisions

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Multi-particle production is described in terms of color of strings stretched between the partons of the projectile and target. Color strings will decay into new ones by $q\bar{q}$, $qq - \bar{q}\bar{q}$ production.

$$S_1 = \pi r_0^2, \quad r_0 \sim 0.25 \text{ fm}.$$
The number of strings grows with the energy and with the number of nucleons of participating nuclei. Color strings may be viewed as small disks in the transverse space filled with the color field created by colliding partons. Particles are produced by the Schwinger mechanisms. With growing energy and size of the colliding nuclei the number of strings grow and start to overlap forming clusters. At a critical density a macroscopic cluster appears and marks the percolation phase transition.
The formation of clusters behaves like disks in the continuum two dimensional percolation.

- $\eta_t^c = 1.1 - 1.5$
- $\eta_t = N_s S_1 S_A$
- We assume a cluster of $n$ strings behaves as a single string with higher color field, and momentum.

- $<\mu_n> = \sqrt{\frac{nS_n}{S_1}} <\mu_1>$
- $<p_{Tn}^2> = \sqrt{\frac{nS_1}{S_n}} <p_{T1}^2>$
In SPM the relevant quantity is the transverse impact parameter density $\eta^t$ for pp collisions

$\eta^t \equiv (\frac{r_0}{R_p})^2 \bar{N}_p$

The particle density $dn/dy$ at mid rapidity is related to the average number $\bar{N}_s$ of strings

$$\frac{dn}{dy} \sim F(\eta^t) \bar{N}_s$$

$$F(\eta^t) = \sqrt{\frac{1-e^{-\eta^t}}{\eta^t}}$$
The overlap area is given by \( S_{NA} = S_A (N_A/A)^{5/3} \),

\[
N_A^s \simeq N_p^s N_A^{(\alpha+1)}
\]

with

\[
N_p^s = 2 + 4 \left( \frac{r_0}{R_p} \right)^2 \left( \frac{\sqrt{s}}{m_p} \right)^{2\lambda},
\]
Notice that it would be expected

\[ N_A^s \simeq N_p N_A^{4/3} \]  \hspace{1cm} (3)

instead of

\[ N_A^s = N_p N_A^{(\alpha+1)} \]  \hspace{1cm} (4)

but the energy in pp is \( \sqrt{s} \) and in AA is \( A\sqrt{s} \), therefore at not very high energy some strings have not enough energy to be formed. The number should increase from \( A \) to \( A^{4/3} \) with a \( \ln s \) (phase space) dependence as is has \( \alpha(s) \).
With the string density

\[ \eta_{tA}^t = \eta_{tP}^t N_A^{(\alpha(s))} \frac{A}{N_A^{2/3}} \]  

(5)
\[
\frac{1}{N_A} \left. \frac{dn}{dy} \right|_{y=0} = \left. \frac{dn_{pp}}{dy} \right|_{y=0} \left( 1 + \frac{F(\eta^t_{NA})}{F(\eta^t_p)} (N_A^{\alpha(\sqrt{s})} - 1) \right), \quad (6)
\]

with

\[
\alpha(s) = \frac{1}{3} (1 - \frac{1}{1 + \ln(\sqrt{s}/s_0 + 1)}), \quad (7)
\]

and

\[
\left. \frac{dn_{ch}^{pp}}{d\eta} \right|_{\eta=0} = \kappa F(\eta^t_p) N_p^s, \quad (8)
\]
Figure: Multiplicity dependence on $\sqrt{s}$. Data from $p - p$, $Cu - Cu$, $Au - Au$ and $P - Pb$ is shown in circles, triangles and starts respectively. $(N_A = 1, A = 1)$ for $pp$ (grey line); $(N_A = 50, A = 63)$ for $CuCu$ (blue line); and $(N_A = 175, A = 200)$ for $AuAu/PbPb$ (red line).
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\[ \tilde{N}_s \sim e^{2\lambda Y}, \quad (9) \]

for the particle density, at \( y \approx 0 \),

\[ \frac{dn}{dy} \sim e^{\lambda Y}, \quad (10) \]

and for the full rapidity distribution,

\[ \frac{dn}{dy}|_{pp} = a e^{\lambda Y} \frac{dn}{dy}|_{s}, \quad (11) \]

where \( \frac{dn}{dy}|_{s} \) is the single string density, \( \frac{dn}{d\eta}|_{pp} \)

\[ \frac{dn}{dy}|_{s} = \frac{1}{e^{\frac{\eta-(1-\alpha)Y}{\delta}} + 1}, \quad (12) \]
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\[ \frac{dn}{d\eta}|_{pp} = J \frac{dn}{dy}|_{pp}, \quad (13) \]

with \( J = \frac{\cosh \eta}{\sqrt{k + \sinh^2 \eta}} \), \( k = \frac{m^2 + p_T^2}{p_T^2} \) and by assumption fix \( k \) at the effective value 1.2. It corresponds to \( m_\pi \simeq 0.14 \) GeV and \( \bar{p}_\pi \simeq 0.3 \) GeV.
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\[
\left. \frac{d\eta_{pp}}{d\eta} \right|_{\eta} = \kappa' J F(\eta_p^t) N_p^s \frac{1}{\exp \left( \eta - \frac{(1-\alpha)Y}{\delta} \right) + 1}
\]

(14)

Comparison of the results from the evolution of the \( \frac{d\eta_{ch}}{d\eta} \) with dependence in pseudorapidity for \( p - p \) collisions at different energies (lines).
Evolution in pseudorapidity for AA collisions

\[
\kappa' J(N_A) \frac{dn^{pp}}{dy} \bigg|_{y=0} (1 + \frac{F(\eta^t_{NA})}{F(\eta^t_p)} (N_A^{\alpha(\sqrt{s})} - 1)) \frac{1}{\exp \left( \frac{-\eta - (1-\alpha)Y}{\delta} \right) + 1}
\]

with \( \kappa' = \frac{\kappa}{J(\eta=0)} \left( \exp \left( \frac{-(1-\alpha)Y}{\delta} \right) + 1 \right) \).
In all the computations we have used the following values of the parameters: \( \kappa = 0.63 \pm 0.01 \), \( \lambda = 0.201 \pm 0.003 \), \( \sqrt{s_0} = 245 \pm 29 \) GeV, \( \alpha \approx 0.34 \), \( \delta \approx 0.84 \) and \( k_1 = 1.2 \) to describe the particle density \( \frac{dn}{d\eta}|_{NN_A} \) in the same power law as \( \frac{dn}{d\eta}|_{pp} \). We had made here an extension to these descriptions to add the pseudo rapidity evolution.
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Figure: Evolution of the $dn_{ch}/d\eta$ with pseudorapidity for Cu-Cu collisions at 22.4 GeV, 62.4 GeV, and 200 GeV energies, data from ref. [1]. 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, black lines show our results.
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Figure: Evolution of the $dn_{ch}/d\eta$ with pseudorapidity for Au-Au collisions at 19.6 GeV, 62.4 GeV, 130 GeV and 200 GeV energies. 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, black lines are the model results [2]
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Figure: Comparison of the results CMS [3] from the evolution of the \( \frac{dn_{ch}}{d\eta} \left( \frac{1}{N_{part}/2} \right) \) with the pseudorapidity for Pb-Pb collisions at 2.76 TeV. Error bars in color green, blue, pink and red are used for the corresponding centralities 85 – 95%, 50 – 55%, 0 – 90% and 0 – 5% respectively, lines in black are the corresponding results from the model to the respective centrality, for the smaller centrality we use the number of participants corresponding to the 85-95% showed in dot and dashed line and in dashed line is the minimum number of participants equal 2.
Figure: Predictions on the evolution of the $\frac{dn_{ch}}{d\eta} (\frac{1}{N_{part}/2})$ with pseudorapidity for Pb-Pb collisions at 3.2, 3.9 and 5.5 TeV energies at 0 – 5% centrality.
We have discussed in a general way the physics of particle densities in pp and AA collisions.

Our model gives a non-linear dependence of \( \frac{1}{N_A} \frac{dn}{d\eta}|_{AA} \) on \( \frac{dn}{d\eta}|_{pp} \).

Particle densities, as a function of \( \eta \) and \( Y \) give a good description of Pb-Pb data at LHC in a wide region in \( \eta \). The same is observed for pp in a wide range of rapidity \( Y \).

Notice that recent data from TOTEM experiment measurements in the charged particle pseudorapidity density \( dN_{ch}/d\eta \) in pp collisions at \( \sqrt{s} = 7 \) TeV for \( 5.3 < |\eta| < 6.4 \) is consistent with this results.
Thank you...
Bibliography


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