Forward Backward Multiplicity Correlations in $pp$ collisions at LHC Energies

Shaista Khan
Aligarh Muslim University
Aligarh, INDIA

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Outline

- Introduction
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Forward-backward (FB) multiplicity correlations among the charged particles produced in different pseudorapidity, $\eta$, regions are regarded as a powerful tool for understanding the underlying mechanism of particle production in high energy h-h, h-A and A-A collisions.

FB multiplicity correlations observed in the past decades have been interpreted using the concept of clustering, i.e. the particle production take place via the formation of some intermediate states, referred to as “clusters” which finally decay isotropically, in their center of mass frame, to real physical hadrons.

By examining $k$-particle angular correlations, information regarding various properties of clusters, e.g., number of clusters produced on e-b-e basis, mean cluster multiplicity, size of clusters and the extent to phase space occupied by their decay products etc. may be extracted.
The inclusive two-particle correlations have two components:
Short Range Correlations (Confined to $\eta \sim \pm 1$)
Long Range Correlations (extend over a relatively larger range $>2$ units of $\eta$)

SRCs ➔ Arise due to the tendency of the secondary particles to be grouped in clusters, which finally decay isotropically to real physical hadrons.

LRCs ➔ Arise due to e-by-e fluctuations of overall particle multiplicity at relatively higher incident energies.

In the case of AA collisions, LRCs induced across a wide range in $\eta$ are expected to reflect the earliest stages of the collisions, almost free from final state effects.

In pp collisions by studying the dependence of FB correlations on particle pseudorapidity, collision energy and transverse momenta.
Details of Data

- Monte Carlo events samples (10$^6$ events) corresponding to LHC energies $\sqrt{s} = 0.9$, 2.76, 7.0 and 13.0 TeV are simulated using codes AMPT-v1.21-v2.21 and HIJING-1.35.
- Events with $n_{\text{ch}} \geq 10$ are selected for the analysis.
- Pseudorapidity cut used: $-1 \leq \eta_c \leq +1$
- $p_T$ cut used: $0.3 < p_T < 1.5$ GeV/c
The linear dependence of mean charged particle multiplicity in backward $\eta$ region ($<n_B>$), on the multiplicity of charged particles in the forward $\eta$- region ($n_F$) as,

$$\langle n_B \rangle = a + b_{\text{corr}} \cdot n_F$$  \hspace{1cm} (1)

For symmetric F-B regions, the correlation strength, $b_{\text{corr}}$ is,

$$b_{\text{corr}} = \frac{\langle n_B n_F \rangle - \langle n_B \rangle \langle n_F \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2} = \frac{D_{BF}^2}{D_{FF}^2}$$  \hspace{1cm} (2)

Where $D_{BF}$ and $D_{FF}$ respectively, denote the backward-forward and forward-forward dispersions.

➢ Pseudorapidity, $\eta$ distributions of charged particles is divided into two parts with respect to its centre of symmetry, $\eta_c$ ($\eta = 0$).

➢ The region having values $\eta < \eta_c$ is referred to as the backward (B) region while the region having $\eta > \eta_c$ is termed as forward (F) region.

➢ Number of charged particles emitted in F and B regions, $n_F$ and $n_B$ on event-by-event (ebe) basis are counted.

➢ The window width is then increased in steps of 0.2 till the region $\delta\eta = \eta_c \pm 0.8$ is covered.

➢ For each $\eta$-window, values of $n_F$ and $n_B$ are calculated to study the dependence of correlation strength $b_{\text{corr}}$ on $\eta$-bin width ($\delta\eta$) and as a function of the gap between the windows ($\eta_{\text{gap}}$).
Results

Forward vs backward multiplicity distribution at $\sqrt{s} = 13.0$ TeV is shown for the AMPT (left) and HIJING (right) events.
The straight lines in the figure represent the best fits to the data from Eq. 1.

Similar deviations were observed for pp data at $\sqrt{s} = 7.0$ TeV
A deviation from the linearity for higher $n_F$ values is observed for AMPT and HIJING events.
The values of $b_{\text{corr}}$, from Eq. 1 and Eq. 2 are nearly the same and exhibit strong F-B correlation.

Values of $b_{\text{corr}}$ increases with increasing collision energy.

HIJING gives somewhat smaller values of $b_{\text{corr}}$ as compared to those predicted by AMPT.

<table>
<thead>
<tr>
<th>$\sqrt{s}$ (TeV)</th>
<th>$b_{\text{corr}}$ (linear fit)</th>
<th>$b_{\text{corr}} (= D_{BF}^2/D_{FF}^2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AMPT</td>
<td>HIJING</td>
</tr>
<tr>
<td>0.9</td>
<td>0.349 ± 0.001</td>
<td>0.214 ± 0.001</td>
</tr>
<tr>
<td>2.76</td>
<td>0.447 ± 0.001</td>
<td>0.223 ± 0.001</td>
</tr>
<tr>
<td>7.0</td>
<td>0.558 ± 0.001</td>
<td>0.247 ± 0.001</td>
</tr>
<tr>
<td>13.0</td>
<td>0.643 ± 0.001</td>
<td>0.260 ± 0.001</td>
</tr>
</tbody>
</table>
Dependence of correlation strength on gap between the windows
For each $\sqrt{s}$, the FB correlation strength is decreasing slowly with increasing $\eta_{\text{gap}}$.

The growth of the $b_{\text{corr}}$ is observed with the increase of collisions energy from 0.9 to 13TeV.

The slopes of $b_{\text{corr}}$ does not affect. The contribution of the short-range correlations has a very weak $\sqrt{s}$ dependence.

LRCs plays a dominant role and its strength increases with the increase in collision energy.

Value of $b_{\text{corr}}$ with $\eta_{\text{gap}}$ for different windows widths $\delta\eta = 0.2, 0.4, 0.6$ and 0.8 at different energies are plotted for AMPT data sets and compare the results with real data.

[ALICE, J. of High En. Phys. 05 (2015) 097]
Similar trends of variation is shown by HIJING events but somewhat smaller values of $b_{\text{corr}}$ as compared to those predicted by AMPT.
Dependence of correlation strength on window width
The correlation strength $b_{corr}$ increases non-linearly with increase in the window width $\delta \eta$, for all collision energies.

The trend is quite well described by the AMPT and HIJING data sets but HIJING gives somewhat smaller values as compared to the AMPT.
Dependence of correlation strength on the collision energy
The comparison of $b_{\text{corr}}$ as a function of $\eta_{\text{gap}}$ for $\delta \eta = 0.2$ at $\sqrt{s} = 0.9, 2.76, 7.0$ and $13.0$ TeV with the results obtained from AMPT and HIJING.

The values of $b_{\text{corr}}$ increases with $\sqrt{s}$.

AMPT shows higher values as compare to HIJING but the trend of variations are same.

The values of $b_{\text{corr}}$ at $\sqrt{s} = 0.9$ TeV shows smaller variations while the large discrepancies are observed at higher collision energies.
Correlation strength $b_{\text{corr}}$ with $<n_F>$ and the corresponding values of $\delta \eta$ in pp collisions at 0.9, 2.76, 7.0 and 13.0 TeV for the HIJING and AMPT data sets.

<table>
<thead>
<tr>
<th>$\sqrt{s}$ (TeV)</th>
<th>$\delta \eta$</th>
<th>$&lt;n_F&gt;$</th>
<th>$b_{\text{corr}}$</th>
<th>$\delta \eta$</th>
<th>$&lt;n_F&gt;$</th>
<th>$b_{\text{corr}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9</td>
<td>0.565</td>
<td>2.07</td>
<td>0.271 ± 0.007</td>
<td>0.405</td>
<td>2.07</td>
<td>0.313 ± 0.007</td>
</tr>
<tr>
<td>2.76</td>
<td>0.525</td>
<td>2.07</td>
<td>0.283 ± 0.006</td>
<td>0.317</td>
<td>2.07</td>
<td>0.324 ± 0.007</td>
</tr>
<tr>
<td>7.0</td>
<td>0.445</td>
<td>2.07</td>
<td>0.285 ± 0.006</td>
<td>0.207</td>
<td>2.07</td>
<td>0.338 ± 0.007</td>
</tr>
<tr>
<td>13.0</td>
<td>0.41</td>
<td>2.07</td>
<td>0.287 ± 0.007</td>
<td>0.155</td>
<td>2.07</td>
<td>0.344 ± 0.007</td>
</tr>
</tbody>
</table>
The ratio of $b_{\text{corr}}$ at 2.76 and 7.0 TeV with respect to 0.9 TeV vs. $\eta_{\text{gap}}$ for AMPT simulated events in $0.3 < p_T < 1.5$ (GeV/c) is shown.

The multiplicity correlation strength $b_{\text{corr}}$, shows linear increase with $\eta_{\text{gap}}$ for the AMPT data sets.

Similar deviations were observed for pp data at 7.0 TeV [ALICE, J. of High En. Phys. 05 (2015) 097]

$b_{\text{corr}}$ shows almost constant values with $\eta_{\text{gap}}$ for the HIJING events. 

($\delta\eta$ bin-width = 0.2)
Red Points = Ratio between values of $b_{corr}$ at 13 TeV and 0.9 TeV
Green Points = Ratio between values of $b_{corr}$ at 7 TeV and 0.9 TeV
Dependence of correlation strength on $p_T$ intervals
Strong non-linear dependence of $b_{\text{corr}}$ on the size of pseudorapidity windows and on the mean multiplicity in the window.

In order to check the $p_{\text{T}}^{\text{min}}$ dependence on $b_{\text{corr}}$, we use five $p_{\text{T}}$ intervals with the same $<n_{\text{ch}}>$.

$p_{\text{T}}$ intervals within $0.3 < p_{\text{T}} < 6$ GeV/c for window width $\delta \eta = 0.2$ are: 0.3 – 0.39, 0.39 – 0.502, 0.502 – 0.66, 0.66 – 0.95, 0.95 – 6.0 (GeV/c).

ALICE collaboration, which reported an increase in the multiplicity correlation strength with $p_{\text{T}}^{\text{min}}$.

[ALICE, J. of High En. Phys. 05 (2015) 097]
FB correlation strength increases with the transverse momentum if $p_T$ intervals with the same mean multiplicity are chosen.
Dependence of $b_{\text{corr}}$ as a function of $\eta_{\text{gap}}$ for different $p_T$ intervals at 7.0 TeV for pseudorapidity window of width $\delta\eta = 0.2$ for the AMPT and HIJING data.

The values of $b_{\text{corr}}$ increases with higher $p_T^{\text{min}}$ for $\eta_{\text{gap}} = 0$.

[ALICE, J. of High En. Phys. 05 (2015) 097]
Conclusions

- FB correlation strength increases with the increase in collision energy.

- Strong non-linear dependence of the Forward-Backward multiplicity correlation coefficient value on the width of the pseudorapidity windows is observed.

- The observed FB correlation strength increases with the transverse momenta.

- The MC event generators AMPT and HIJING are able to describe the general trends of $b_{\text{corr}}$ as a function of $\delta \eta$, $\eta_{\text{gap}}$ and its dependence on the collision energy.

- In $p_T$-dependent analysis of $b_{\text{corr}}$, AMPT describes data reasonably well, while HIJING shows smaller values.

Work is in progress..........
THANK YOU
BACK UP SLIDES
Furthermore, the strength of correlation is estimated in various configurations of azimuthal sectors selected within the symmetric $\eta$-windows.

The $\Phi$-angle sectors are chosen in separated forward and backward pseudorapidity windows of width $\delta\eta = 0.2$ and $\delta\Phi = \pi/4$ as shown.

[ALICE, J. of High En. Phys. 05 (2015) 097]
Similar trends of variation is shown by HIJING events but somewhat smaller values of $b_{corr}$ as compared to those predicted by AMPT.
Correlation strength $b_{corr}$ calculated from Eq. 1 and 2 is plotted against $\eta_{gap}$ at 7.0 TeV.

- The values of $b_{corr}$, from Eq. 1 and Eq. 2 are nearly the same and exhibit strong F-B correlation in both AMPT and HIJING data samples.

- The values of $b_{corr}$ decreases with increasing $\eta_{gap}$.

Correlation strength $b_{\text{corr}}$ calculated from Eq. 1 and 2 is plotted against $\eta_{\text{gap}}$ at 13.0 TeV.