Study of the shape of the near-side peak in two-particle correlations in collisions of pp, p-Pb and Pb-Pb

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Abstract

In this analysis note we study the evolution of the width of the near-side jet-like peak with transverse momentum and multiplicity for pp, p-Pb and Pb-Pb collisions. We perform a long-range extrapolation over small values of $\Delta \eta$ in order to isolate the short-range correlation. We do the analysis for charged hadrons first, and then use identified particles (pions, kaons, protons) to get a better understanding.
1 Introduction

In two-particle correlations we measure the relative distribution of the particle pairs (trigger and associated particle) over $\Delta \eta$ and $\Delta \phi$. $\Delta \phi$ is the difference in azimuthal angle between the particles in the pair in the transverse plane, and $\Delta \eta$ is difference between the particles in pseudorapidity

$$\eta = -\ln[\tan(\frac{\theta}{2})]$$  (1)

with $\theta$ - angle between transverse plane and beam axis. The correlation function is defined as the associated yield per trigger particle [1] [2] [3]:

$$C(\Delta \phi, \Delta \eta) = \frac{1}{N_{\text{trig}}} \frac{d^2 N}{d\Delta \phi d\Delta \eta} = \frac{S(\Delta \phi, \Delta \eta)}{B(\Delta \phi, \Delta \eta)}$$  (2)

It can be expressed as the signal distribution $S(\Delta \phi, \Delta \eta)$ divided by the background distribution $B(\Delta \phi, \Delta \eta)$ where the signal is the yield of particle pairs coming from the same event and the background is the yield coming from mixed events. These mixed events are chosen to have similar vertex position and multiplicity. Division by $B(\Delta \phi, \Delta \eta)$ is reducing acceptance and efficiency losses which are due to two-track cuts. A constant $\alpha$ is chosen such that $B(0, 0) = 1$ assuming full acceptance and efficiency for pair of particles going in the same directions. No single-track efficiency correction is applied since the width is not expected to be sensitive to it.

2 Motivation

It is known that in pp collisions the correlation function is dominated by a peak centered at $(\Delta \phi, \Delta \eta) \approx (0, 0)$ and is believed to be a result of particles produced by the same fragmenting parton.

In Pb-Pb, however, one can clearly see a so-called double-ridge structure, at $\Delta \phi \approx 0$ and $\Delta \phi \approx \pi$ prolonged over $\Delta \eta$. These ridges are attributed to the collective behaviour of the multiple particles involved in a heavy ion collision [4]. A good attempt the explain that flow is the hydrodynamical model.

To gain a better understanding of the flow and its contribution, we subtract it from the correlation function via extrapolating the long-range contributions in $|\Delta \eta| > 1.2$ over the entire range in $\Delta \eta$. By doing that we separate the hydrodynamical and peak contributions and provide a better quantitative estimate for the peak.

The same analysis is performed for p-Pb which is supposed to be an intermediate case between the first two. When we do the double-ridge analysis in p-Pb we assume that there is no modification of the jet fragmentation with multiplicity. Comparing the results between the three systems should be a good example of how the hydrodynamical effects affect the system as a whole (we do NOT expect any flow in pp).

3 Technical Details

The correlation function is defined for the following bins in $p_T, \text{trigg}$, $p_T, \text{assoc}$ (in GeV/c):

$0.5 - 1 // 1 - 2 // 2 - 3 // 3 - 4 // 4 - 8$.

The multiplicity selection is performed based on the V0M detector response. For example, 0-10% multiplicity class means that we are using the 10% of all registered events which have highest detector response, i.e. highest particle multiplicity per event. In our analysis the following multiplicity classes are present (in %) : 0 - 1 // 0 - 10 // 10 - 20 // 20 - 30 // 30 - 40 // 40 - 50 // 50 - 60 // 60 - 70 // 70 - 80 // 80 - 90 // 90 - 100.
The data sets used are listed below:
- pp : LHC10b_p2_AOD_147, LHC10d_p2_AOD_147, LHC10e_p2_AOD_147;
- p-Pb : LHC13b_pass3, LHC13c_pass2;
- Pb-Pb : LHC10h_AOD086.

For Monte-Carlo simulation studies we take the corresponding data with the following generators:
- pp : Pythia;
- p-Pb : DPM Jet;
- Pb-Pb : Hijing.

These generators, however, do not include collective behaviour as it is simulated with hydrodynamical models.

4 Projecting the Peak and Fitting in $\Delta \phi$ and $\Delta \eta$

The general formula we use to fit the remaining peak is a double Gaussian and a baseline:

$$ a_0 + a_1 e^{-\frac{x^2}{2\sigma_1^2}} + a_2 e^{-\frac{x^2}{2\sigma_2^2}} $$  \hspace{1cm} (3)

The result of the fit is tested with the $\chi^2$ method. In order to achieve a better fit we try several techniques:
- baseline $a_0$ is fixed to zero;
- baseline is fixed to the minimum of the correlation function;
- baseline is fixed to the normalised integral of the correlation function in an area between the two ridges;
- baseline is allowed to move within $\pm 20\%$ of the difference between the peak height and one of the above mentioned estimates (shown on most of the plots);
- for each of the above mentioned baseline estimates we set limits to the values of $a_1$, $\sigma_1$, $a_2$ and $\sigma_2$ using the RMS(Root Mean Square) of the projection;

Moving baseline gives good results, however, for some momentum bins we fix it to check if there is an improvement on the fit or on the uncertainty bars.

Applying these constraints we then use the following fitting options:
- the center of the bin to lie on the curve of the fitting function (standard Root method and the one presented in this report);
- the integral of the fitting function to equal the content of the bin ("I-method" in Root);
- the log-likelihood method.

After we have obtained values from the fit for $a_1$ and $a_2$, we normalize them so that $a_{1,\text{norm}} + a_{2,\text{norm}} = 1$ using:

$$ J = \frac{a_1}{\sqrt{2\pi\sigma_1}} + \frac{a_2}{\sqrt{2\pi\sigma_2}} $$

$$ a_{1,\text{norm}} = \frac{a_1}{\sqrt{2\pi\sigma_1}J} \hspace{1cm} a_{2,\text{norm}} = \frac{a_2}{\sqrt{2\pi\sigma_2}J} $$  \hspace{1cm} (5)

Then we can calculate the combined gaussian width $\sigma_{\text{comb}}$ as:

$$ \sigma_{\Delta i,\text{comb}} = \sqrt{a_{1,\text{norm}}^2\sigma_{\Delta i,1}^2 + a_{2,\text{norm}}^2\sigma_{\Delta i,2}^2} $$  \hspace{1cm} (6)

where $i$ the corresponding projection in $\Delta \phi$ or $\Delta \eta$. Results that follow in this report use $\sigma_{\text{comb}}$ as a default variable respectively in $\Delta \phi$ and $\Delta \eta$. 
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Fig. 1: Left: per-trigger yield as function of $\Delta \phi$ and $\Delta \eta$ after long-range subtraction. Center and Right: its projections in $\Delta \phi$ and $\Delta \eta$. The red line is the fit and the dotted lines show its components - 2 gaussians and a baseline.

5 Results

We obtained results for the widths $\sigma_{\Delta \phi}$ and $\sigma_{\Delta \eta}$ in collisions of pp, p-Pb and Pb-Pb. Only one of them is presented as an example of the work done and the rest are available in the ALICE Collaboration database.

Fig. 2: Width $\sigma_{\Delta \eta}$ as a function of multiplicity classes in p-Pb collisions for all studied transverse momenta. Colours represent different $p_T^{\text{trigg}}$, while markers different $p_T^{\text{assoc}}$ for the same trigger particle.
The general tendency that can be observed in p-Pb collisions (see Fig.2) is a decreasing trend with increasing particle momentum and no or only very little dependence on the event multiplicity. An exception is the very low momentum bin $0.5 \leq p_{T,\text{trigg}},\ p_{T,\text{assoc}} \leq 1$. A slight decrease with decreasing the multiplicity class can be observed in Pb-Pb, esp. for $\Delta \eta$. Previous research on this topic is done [5].

5.1 Comparing the three systems at same momentum

The three systems pp, p-Pb and Pb-Pb are observed to behave in the same way at high momentum (see Fig.3):

![Fig. 3: Width $\sigma_\phi$ (left) and $\sigma_\eta$ (right) as a function of multiplicity classes in pp, p-Pb and Pb-Pb collisions for $4.0 \leq p_{T,\text{trigg}} \leq 8.0$, $4.00 \leq p_{T,\text{assoc}} \leq 8.0$.](image)

There is a significant difference, however, at low momentum (see Fig.4). In Pb-Pb collision an increase of the width in $\Delta \eta$ at higher multiplicities is observed, which we believe might be caused by collective behaviour effects. For more peripheral collisions, i.e. those with lower multiplicity, the effects are not that strong and Pb-Pb approaches the other two systems.

![Fig. 4: Width $\sigma_\phi$ (left) and $\sigma_\eta$ (right) as a function of multiplicity classes in pp, p-Pb and Pb-Pb collisions for $2.0 \leq p_{T,\text{trigg}} \leq 3.0$, $2.00 \leq p_{T,\text{assoc}} \leq 3.0$.](image)

Applying a fixed-baseline fit we manage to reduce the uncertainty (see Fig.5), but the difference is still observed.
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Fig. 5: Width $\sigma_\Delta\phi$ (left) and $\sigma_\Delta\eta$ (right) as a function of multiplicity classes in pp, p-Pb and Pb-Pb collisions for $2.0 \leq p_{T,\text{trigg}} \leq 3.0$, $2.0 \leq p_{T,\text{assoc}} \leq 3.0$ with a fixed baseline.

5.2 Comparing results from Monte-Carlo simulations

A comparison between the Monte-Carlo simulations for pp, p-Pb and Pb-Pb (see Fig.6) shows that they behave similarly. This is expected because the Hijing simulation in Pb-Pb does not include any collective behaviour and therefore flow contributions.

Fig. 6: Width $\sigma_\Delta\phi$ (left) and $\sigma_\Delta\eta$ (right) as a function of multiplicity classes from MC simulations for pp (Pythia), p-Pb (DPMJet) and Pb-Pb (Hijing) collisions for $2.0 \leq p_{T,\text{trigg}} \leq 3.0$, $2.0 \leq p_{T,\text{assoc}} \leq 3.0$.

5.3 Particle Identification PID

Using particle identification we can measure the width of the correlation between hadrons and pions, kaons or protons. The statistics available is large for pions and kaons, but smaller for protons, where the peak is not easily observed. That affects the fit and increases the uncertainty of the measurement.
6 Conclusions

Long-range subtraction is needed to isolate the jet-like near-side peak in p-Pb and Pb-Pb collisions. The three systems show very similar results at high momentum, but significantly different at low momentum. That difference can be attributed to hydrodynamical effects. These effects are not reproduced in the Monte-Carlo simulations considered, since no collective behaviour conditions are implemented in these simulations. Further work should concentrate on increasing the statistics and improving the fit in order to reduce the large uncertainty of some measurements.

References

[1] "Long-range angular correlations on the near and away side in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV", ALICE Collaboration, 03 Dec 2012
[2] "Observation of long-range, near-side angular correlations in p-Pb collisions at the LH", The CMS Collaboration
[3] "Observation of Associated Near-side and Away-side Long-range Correlations in $\sqrt{s_{NN}} = 5.02$TeV Proton-Lead Collisions with the ATLAS Detector", The ATLAS Collaboration