

Effect of hard processes on momentum correlations in pp and p \bar{p} collisions

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Abstract The HBT radii extracted in pp and p \bar{p} collisions at SPS and Tevatron show a clear correlation with the charged particle rapidity density. We propose to explain the correlation using a simple model where the distance from the initial hard parton-parton scattering to the hadronization point depends on the energy of the partons emitted. Since the particle multiplicity is correlated with the mean energy of the partons produced we can explain the experimental observations without invoking scenarios that assume a thermal fireball. The model has been applied with success to the existing experimental data both in the magnitude and the intensity of the correlation. The model has also been extended to pp collisions at the LHC energy of 14 TeV. The possibilities of a better insight into the string spatial development using 3D HBT analysis are discussed.

Key words HBT • correlations • proton-proton collisions • hadronization

Introduction

The size of the source created in pp and p \bar{p} collisions, as measured with momentum correlations, increases with particle multiplicity [1, 9]. The correlation of the extracted size with the rapidity density of the collisions, from the HBT analysis, was sometimes described as evidence for the existence of a “source” with a given size. Some alternative explanations have been given invoking long-lived resonances and multiple parton interactions [2].

In the present work, we are investigating whether the observed behavior may be understood in terms of more trivial explanations related to the details of the hadronization of the partons leading to jets. We know namely, that the point of hadronization of a jet and the point of the initial parton-parton hard scattering do not coincide. The distance between them is the so-called hadronization length (L_{hadr}).

Numerical estimates for the time scale of hadronization vary significantly [3, 5, 10], but owing to the Lorentz boost to the laboratory frame, they are proportional to the energy, $L_{\text{hadr}} \propto O(1)E_t$ ([11]). Hence, there is a dependence of L_{hadr} on the energy due to the Lorentz boost. On the other hand, the energy spectrum of the emitted jets depends on the charged particle multiplicity of the events. Hence, if we assume that the hadronization occurs at different distances from the initial hard scatterings, depending on the energy of the jet, we can expect that this effect may simulate an extended hadronic source without invoking the presence of a thermalized source of hadrons. We have followed this line of thought in the present work.

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Table 1. Dependence of OSL radii on f_j and f_t for the $\langle dN_{ch}/d\eta \rangle = 23.0$. The fits were made imposing a double Gaussian (Eq. (1)) on 1D projections, taking two other components >50 MeV. In the rows where R_2 is not specified, fits did not converge and a single Gaussian is used instead

f_j	f_t	R_{o1} [fm]	λ_{o1}	R_{o2} [fm]	λ_{o2}	R_{s1} [fm]	λ_{s1}	R_{s2} [fm]	λ_{s2}	R_{j1} [fm]	λ_{j1}	R_{j2} [fm]	λ_{j2}
0.2	0.2	0.82	0.55	–	–	1.33	0.61	–	–	1.28	0.58	–	–
0.25	0.25	0.92	0.50	–	–	1.51	0.55	–	–	1.44	0.53	–	–
0.3	0.3	1.02	0.47	–	–	1.65	0.52	–	–	1.56	0.50	–	–
0.4	0.4	2.12	0.23	0.84	0.23	2.02	0.44	0.51	0.03	2.42	0.40	0.75	0.09
0.5	0.5	2.30	0.24	0.79	0.19	2.22	0.42	0.40	0.03	2.47	0.37	0.61	0.08
0.6	0.6	2.70	0.19	0.87	0.17	2.77	0.31	1.01	0.08	3.11	0.28	1.04	0.12
0.8	0.8	2.88	0.21	0.67	0.11	2.84	0.28	0.69	0.05	3.41	0.25	0.84	0.09
1.0	0.6	3.03	0.25	0.66	0.11	2.75	0.28	0.67	0.06	3.00	0.27	0.78	0.09
1.4	0.5	3.52	0.25	0.64	0.09	2.55	0.26	0.75	0.06	2.89	0.23	0.86	0.09

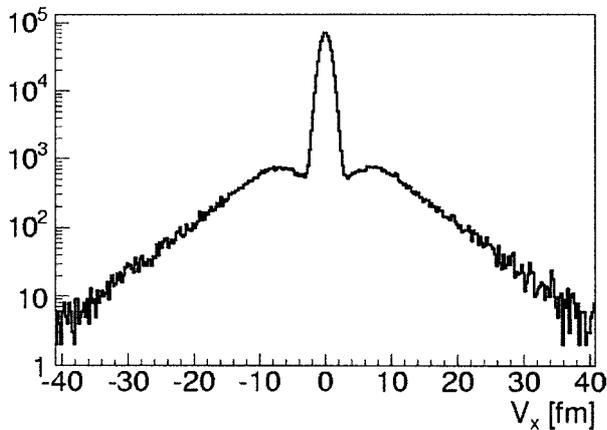


Fig. 2. Cross-section through the 2D distribution of the hadronization points in the plane perpendicular to the beam. The difference in height between contributions from the “underlying event” (the peak for values around 0) and jets (shoulders) is a phase space effect. In fact, the majority of particles originate from jets. The dynamic width jet geometry with $f_j = 1.0$, $f_t = 0.6$ and $\langle dN_{ch}/d\eta \rangle = 12.4$.

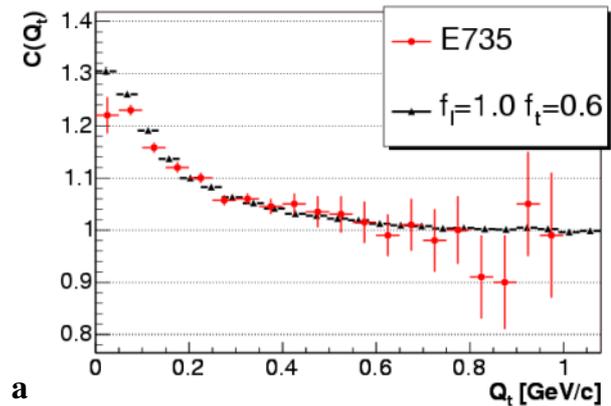
parameters that gives a good agreement with E735 result. Within some range we can decrease f_j and find such a value of f_t , such that we still reproduce the experimental result (Fig. 5b).

We believe that the precision of the determination of f values could be improved if results of a 3D HBT analysis were available. Namely, the dependence of R_{out} and R_{side} on event multiplicity is required. We have found that R_{side} increases together with f_t , and R_{out} together with f_j (see Table 1). This means that we can estimate the size of the jet fragmentation volume using the three-dimensional correlation analysis.

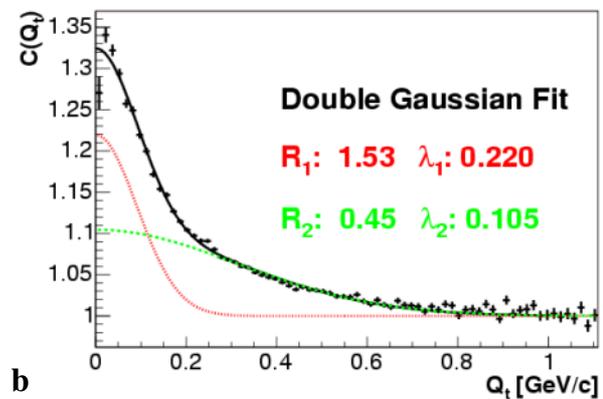
In our model, the “underlying event” (UE) is somewhat overestimated since we have imposed the cut on the jets of less than 3 GeV and this part has been added to the UE. We have examined how our results change if we reduce UE by removing randomly 50% of particles not assigned to jets. We have found that the obtained radii stay unchanged within 10%.

From Fig. 6, we see that the correlation functions extend up to large Q 's (0.4–1.0 GeV), similarly to the

ones obtained by E735. The slope of the “tail” depends on the multiplicity. The simulated correlation function cannot be well represented by a single Gaussian as expected from the distribution of particle hadronization points shown in Fig. 2. As it can be seen, e.g. in Fig. 4c, a better fit of the correlation function is obtained using a double Gaussian, albeit it is not yet probably the exact form of a correlator for this kind of source. The two



a



b

Fig. 3. a – The Q_t correlation function from our model compared with the correlation function extracted from [1] ($\langle dN_{ch}/d\eta \rangle = 12.5$) and b – double Gaussian fit to it. The dynamic width jet geometry with $f_j = 1.0$, $f_t = 0.6$ and $\langle dN_{ch}/d\eta \rangle = 12.4$.

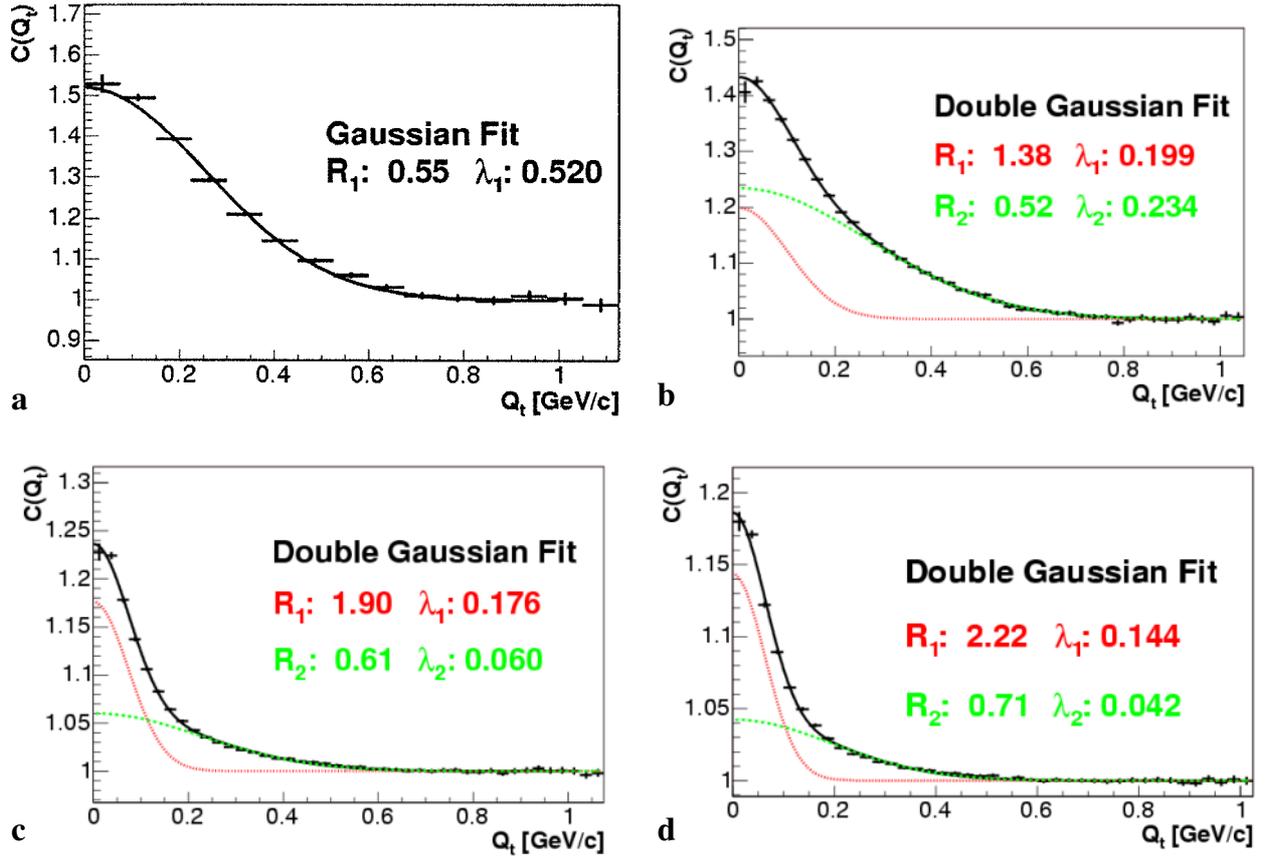


Fig. 4. Q_t correlation functions for the case of the dynamic width geometry with $f_l = 1.0$ and $f_t = 0.6$; a – $\langle dN_{ch}/d\eta \rangle = 3.2$, b – $\langle dN_{ch}/d\eta \rangle = 7.3$, c – $\langle dN_{ch}/d\eta \rangle = 17.2$, d – $\langle dN_{ch}/d\eta \rangle = 23.0$.

radii may be understood in term of the smaller one representing the correlations among the particles from the “underlying event” and the larger one representing the correlations of jet particles with the ones of the “underlying event”, although the interplay of the different factors make such a representation only partially true.

It is important to mention that the extracted radii are much smaller than the extent of the source due to the fact that the particles from the “underlying event” are traveling, while the jet did not yet hadronize! Similarly, particles hadronizing first within a jet also move together with not yet hadronized partons. The

same argumentation also explains the weak dependence of R_t on f_l in the “tube geometry”.

Fitting such a correlation function with a single Gaussian – as was done in E735 – brings large uncertainties (Fig. 6), because the obtained result is very sensitive to the normalization chosen (at which point correlation function crosses 1). To be able to compare with the experimental results [1, 9] we have nevertheless used the single Gaussian fit. The results of the double Gaussian fits are shown in Figs. 3 and 4.

Finally, we have calculated, using the parameters extracted for the Tevatron data, the expected correla-

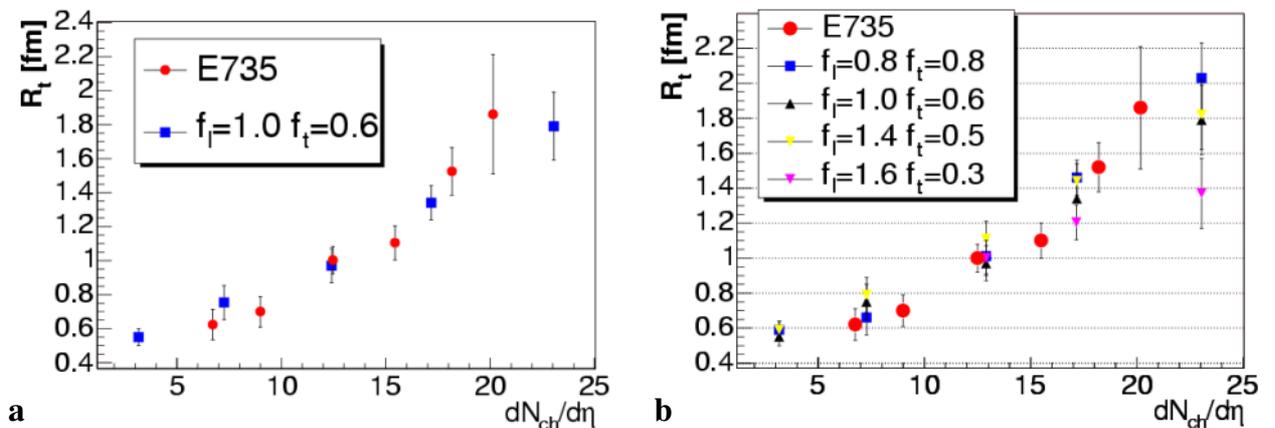


Fig. 5. Results of our model compared to E735 result. The left hand plot shows the best fit to the data obtained with $f_l = 1$ and $f_t = 0.6$, while the right hand plot demonstrates the variation of the results with varying the f values.

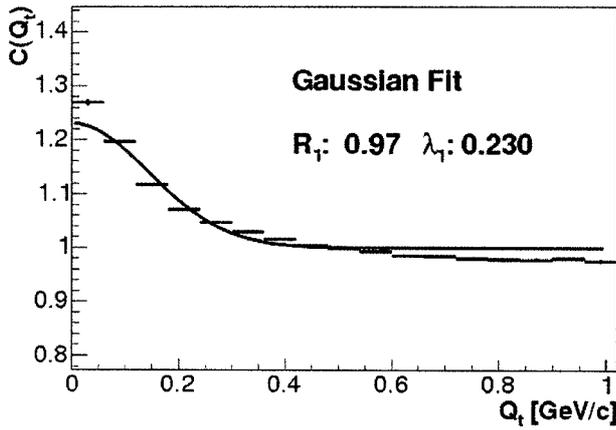


Fig. 6. The same as in Fig. 3, normalized at $Q_t \sim 500$ MeV and fitted with the single Gaussian form of the correlator.

Table 2. R_t radii dependence on $\langle dN_{ch}/d\eta \rangle$ at $\sqrt{s} = 14$ TeV, $f_i = 1.0$ and $f_i = 0.6$. The correlation functions were fitted with the double Gaussian form of the correlator (see Eq. (1))

$\langle dN_{ch}/d\eta \rangle$	R_{t1} [fm]	λ_1	R_{t2} [fm]	λ_2
3.4	1.15	0.15	0.50	0.41
7.6	1.38	0.20	0.52	0.21
12.5	1.70	0.18	0.58	0.09
17.4	1.95	0.15	0.65	0.05
22.4	2.24	0.12	0.73	0.03
27.4	2.91	0.10	0.95	0.04
37.0	3.33	0.07	1.15	0.02

tion of radii with charged particle multiplicities for the maximum LHC energy of 14 TeV. In Table 2, we present results of our model obtained at LHC energies.

Conclusions

Using a simple approach which introduces a dependence of the distance of the mean hadronization points of a parton on its energy we have been able to reproduce very satisfactorily both the dependence of the radii and the trend of the correlation strength λ with the rapidity density in pp collisions. The present results indicate that there is a possibility of an alternative interpretation of the results to those presented in [1] and [4] where the obtained radii are interpreted as evidence for the observation of deconfined matter in pp collisions.

On the other hand, the model a posteriori justifies the hadronization scenario envisaged because the free parameter f has been found close to unity for the range of multiplicities analyzed. We believe that the LHC with its wider range of multiplicities in pp collisions offers interesting possibilities to test our model. We have, therefore, presented here the expected variation of the radii in function of charged particle multiplicities at the LHC. Similarly, the effect of the parton hadronization should be taken into account in the analysis of HBT radii in heavy-ion collisions [7].

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