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PROCEEDINGS

Particle correlations to be seen by ALICE

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Abstract The possibilities of ALICE experiment in measurements of particle correlations are estimated by computer simulations. A dedicated software has been created with the aim to study the influence of different experimental factors on the shape of correlation functions and with the intention to serve in the future for the analysis of real data. A scheme of correlation analysis is described shortly and some of the first results are presented. This analysis is being performed in the frame of ALICE "Physics Performance Report".

Key words ALICE • correlations • HBT • interferometry • Bose-Einstein correlations • quark-gluon plasma

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Space-time evolution of hot and expanding systems created in heavy ion collisions at relativistic energies will be studied by ALICE experiment at the CERN/LHC [2] using momentum correlations of particles emitted with close velocities. As this kind of information is inaccessible by other methods, it will complement the image of collision emerging from the analysis of different observables registered simultaneously.

The ALICE detector will register particle multiplicities never observed before. A huge number of particle pairs will result in very small statistical errors. The elimination of systematic errors will be, therefore, very essential. Final state interaction, especially the Coulomb effects should not be neglected or treated as a "correction factor" [9], but can be used as a source of valuable physical information. In the case of nonidentical particles it will give some new possibilities [5] with respect to ordinary interferometry analysis. On the other hand, the multiparticle Coulomb effects [3] could make analysis of two-particle correlations more complicated.

Small relative momenta in two particle rest frame correspond to close velocities and to small opening angles in the frame of ALICE detection system. The form of measured correlation functions will be influenced by experimental effects of detector acceptance, resolution and efficiency. A very large number of particles registered by ALICE will create a very dense pattern of hits in the detectors. Possible effects of hit sharing and track overlapping can be especially dangerous for the analysis of particle correlations at small relative momenta (close velocities).

A dedicated software has been developed for analysis of momentum correlations at ALICE. We present here some specific points of correlation studies and the first results obtained for simulated and reconstructed correlation effects. The first goal of this work is to verify the possibility of ALICE detection system for measurement of particle correlation parameters. The second is to develop such software tools which could be directly applied for the analysis of real data in the future.

The simulation chain starts from event generation. Commonly used event generators can be applied to produce input data for the analysis of particle correlations. However, all existing event generators are not able to generate events with correlations arising from quantum statistics and final state interaction. These effects should be, thus, added to the standard output of the event generator. The generators like: HIJING, RQMD, UrQMD, NEXUS etc. are based on some physical assumptions and a final stage of the collision is determined by the underlying dynamics. In these cases, the user cannot directly control the particular effects in momentum, angular or multiplicity distributions of generated particles. Therefore, we have applied also a simple event generator MEVSIM [8] which is more suitable for some specific needs of correlation studies. This generator can be useful also for other types of analysis like flow, event-by-event etc.

As mentioned above, the correlation functions constructed with the data taken from any event generator are normally flat in the region of small relative momenta. In order to add the effects of two particle correlations we have applied a special "after-burner", the "HBT processor" [6, 7] which introduces two particle correlations to the selected set of particles, by the shifts of particle momenta. As a result, the generated event can be treated in the same way as a real one in which the correlation effects exist. The HBT processor is an excellent tool to verify the influence of different experimental factors on the shape of two-pion correlation function. Using it for kaons is still justified. In order to apply it for protons the parameterisation of QS+FSI effects is necessary. There are some difficulties with the generation of dynamic effects by multiple application of HBT processor for different intervals of perpendicular momenta, P_t, and rapidity, y. Therefore, we have applied also the method of weights [4] described below.

QS and FSI weights for analysis of particle correlations

In this approach, the correlation function is constructed by calculating weights reflecting particle correlations resulting from quantum statistics (QS) and final state interaction (FSI). The weight is attributed to the pair of selected particles and depends on the space-time coordinates of the emission points and on the four-momenta of both particles. The correlation function is obtained as a ratio of weighted to unweighted distributions, taken as a function of any variable reflecting the particle relative momentum: Q-vector or its components (*out*, *side*, *long*), Q_{inv} etc.

In this way the two-particle correlation function is created pair-by-pair for different types of two-particle systems, identical or nonidentical, taking into account all the details of particle emission process included in the event generator: expansion, flow, resonance production etc. Parameterisation of correlation function is not necessary. This approach can be applied as an after-burner for any dynamical model giving the freeze-out coordinates of the emitted particles: RQMD, NEXUS, UrQMD etc. The space-time evolution and resulting freeze-out coordinates can be also generated separately in order to test some specific scenarios of particle emission.

The simulation procedure consists of four main steps:

1. Generation of events with or without the freeze-out coordinates depending on the model. In the second case the coordinates are generated separately assuming some model of the space-time evolution.
2. Construction of correlation function for generated particles by calculating weights for all two-particle combinations. The ratio of weighted to unweighted distribution of relative momenta is calculated bin-by-bin. The mixing of different events is not necessary at this stage. Obtained correlation function does not contain any experimental factors and can be used as a reference distribution.
3. The weights are attributed to all the pairs of reconstructed and identified tracks. The values of weights calculated in point 2 are used. The reconstruction effects change particle momenta and PID, or/and remove some part of particles due to acceptance, track overlapping and other effects. As a consequence:
   – the weights are attributed to different values of particle momenta (single particle effects);
   – the numbers of pair combinations in different intervals of relative momenta are different than in the generated event (double track effects).

As both effects are correlated in a complicated way, the detailed MC simulation is necessary.

4. The background generation: it can be performed in two ways allowing to study the influence of different experimental factors on the shape of correlation function:
   a) by taking particle pairs from the same events, but without weights;
   b) by taking particle pairs from different events.

In the case a) only the single particle effects influence the shape of correlation function, in the case b) both effects are taken into account.

For practical using, we have applied the approach of Lednický and Lyuboshitz [4] taking the software code developed by R. Lednický. Figure 1 shows a list of two-particle systems for which the calculation of weights can be performed.

Second particle

π^-	π^+	π^0	K^-	K^+	K^0	$\bar{K}^0$	p	n	Λ	d	t	α	First particle
7	5						13						π^-
	7		10	11			12						π^+
		6											π^0
				14			17						K^-
				15			16						K^+
					22								K^0
													$\bar{K}^0$
							2	3	27	9	25	26	p
								1		8	29	30	n
													Λ
										18	24	19	d
											20	21	t
												4	α

Fig. 1. A list of two-particle systems considered for the calculation of QS+FSI weights [4]. The numbers correspond to the pair numbering in the computer code "WSIWLL".

The user has the possibility to switch on/off some particular effects of correlations: QS, strong or Coulomb FSI, influence of Coulomb interaction coming from the emitting source etc. It gives a possibility to verify the role of different effects in the final shape of correlation function. The method of weights can be used effectively for many combinations of two-particle systems being also sensitive to the experimental factors. Note, however, that in this approach the correlation functions are simulated without generating events with correlations. The correlation function is created differently than in the future analysis of the real data.

As two approaches discussed above: generation of events with two-particle correlations and attributing QS+FSI weights to the pairs of particles, are complementary with respect to our needs, both are used for the analysis of particle correlations at ALICE. Some examples of correlation functions, calculated using the methods of weights, are shown in the next section to indicate the limits of correlation effects expected for ALICE.

Expected correlation effects

Before starting simulations for some selected values of space-time parameters let us realize the limits of correlation effects expected for ALICE. The method of weights was applied to generate correlation functions. A thermal spherical source of particles generated by MEVSIM was used.

The Gaussian distribution of particle sources was assumed with the radius r_0 as a parameter.

Figure 2 presents the form of correlation functions for the pairs of positively charged pions emitted by the sources of indicated sizes: (3, 5, 10, 20) fm. Complete calculations have been performed including QS, strong and Coulomb FSI. For the sake of comparison, the shapes of correlation functions containing only the QS effect are presented for smallest 3 fm and largest 20 fm sizes.

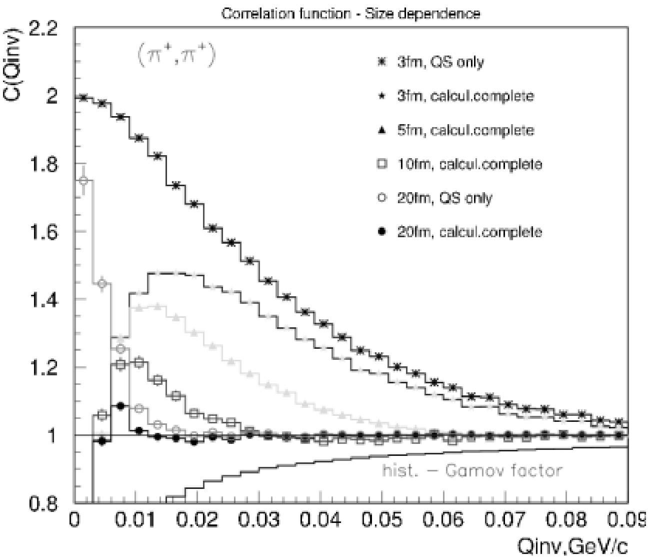

Fig. 2. Correlation functions for $(\pi^+\pi^+)$ system and for the sizes indicated in the Figure. The intercept parameter $\lambda = 1$ was assumed.

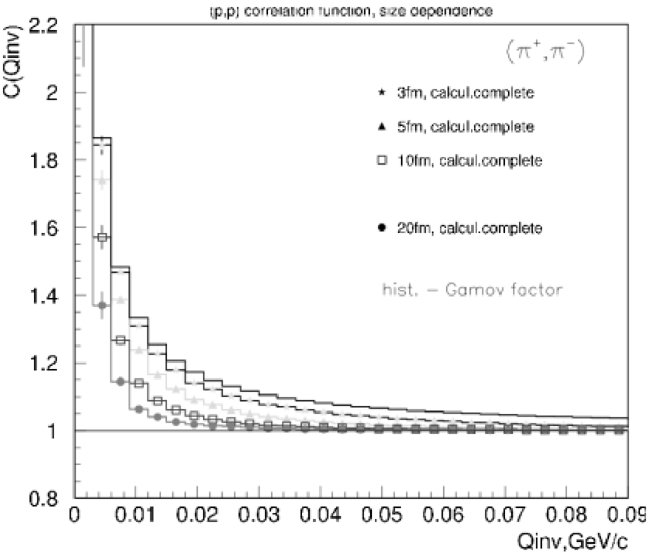

Fig. 3. Correlation functions for different charge pions and for the sizes indicated in the Figure.

For the most expected size of 10 fm, the Q_{inv} region where the correlation functions differ from unity is less than 30 MeV/c and the height is about 1.2 despite the value of the intercept parameter λ equal to one. For the size of 20 fm (full points), the effect of Coulomb repulsion almost completely equilibrate the QS positive correlations giving a very small final effect in the region of 10 MeV/c. The "Coulomb correction" should be in this case much larger than the summary correlation effect itself (see the open circles). It is clear that the traditional approach, in which Coulomb effect is treated as a correction, could not be applied. Note also that the long range Coulomb interaction can reflect different sizes than QS ones. Although such a large size is not expected in the light of the last results from RHIC [1], it is evident that the expected effects should not be located at the edge of experimental possibilities.

Figure 3 shows correlation function for the pairs of different charge pions. In this case, the Coulomb effect determines the shape of correlation function. The behavior of Gamow factor is indicated as a reference. Due to the lack of QS effect and because of large value of the Bohr radius for two-pion system the sensitivity to the sizes are weaker than for identical pions. However, for larger sizes this difference becomes smaller and for the radius of 20 fm the correlation effect for nonidentical pions exceeds that for the identical ones. The correlation effect is localized in the region of very small relative momenta, but note that in the case of $(\pi^+\pi^-)$ pairs the problem of double track resolution is less important, as different charge particles are deviated in different directions by the magnetic field.

The last example, Fig. 4, presents the correlation function for two protons. For this system of two fermions, the effect of QS resulting from Fermi-Dirac statistics leads to negative correlations approaching the value 0.5 for the zero value of Q_{inv}. If the sizes are relatively small, the interplay between the attractive strong interaction and the Coulomb repulsion gives the broad maximum located about Q_{inv} of 40 MeV/c. For larger radii, the size dependence is relatively week. The curve for unrealistic value of 50 fm is shown to demonstrate it.

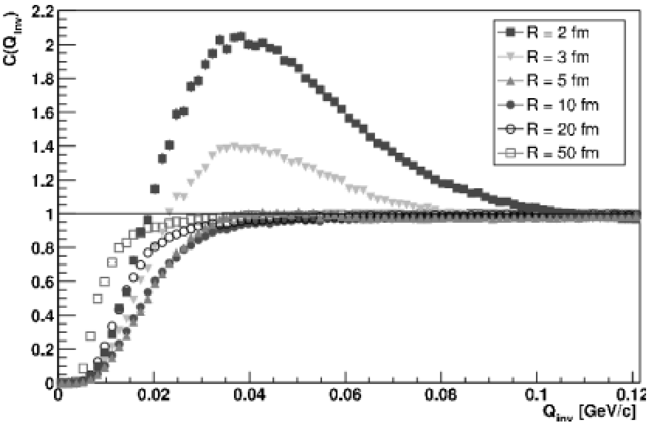

Fig. 4. Correlation functions of two protons for the sizes indicated in the Figure.

Simulation chain for particle correlations

A scheme of simulation chain for analysis of particle correlations at ALICE is illustrated in Fig. 5.

Six blocks are indicated by the letters: a) to f). The upper part of the Figure and the arrows with the empty arrowheads show the flow of data corresponding to the weight method of correlation function calculation. The lower part shows the generation of events with correlations by HBT processor. Thick arrows are common for both methods. The works of different blocks are the following:

a) Event generator. This block represents the generation of particles by an event generator. It gives a list of particles. Each particle is described by its mass, charge and three momentum components (p_x, p_y, p_z). Some generators give also the freeze-out coordinates (x,y,z,t);

b) HBT processor. It changes particle momenta producing events with particle correlations as described above;

c) Transport and reconstruction chain. It simulates the registration of the whole event in details. Each registered particle has been attributed to the PID index, three components of reconstructed momentum (p'_x, p'_y, p'_z) and the index of corresponding generated particle;

d) QS+FSI analyzer. This block generates distributions for the construction of correlation function. Three main kinds of selection are performed: selection of events, particles and particle pairs. All combinations of selected pairs (i_1,i_2) are considered. The vector of momentum difference is calculated in a given (e.g. LCMS, Longitudinally CoMoving System) or in another reference frame. The background distribution is generated with the pairs of particles taken from different events and passing the same selection criteria as the pairs from the same events. This block is constructed on the basis of HBT maker from STAR experiment.

e) QS+FSI weights. This block takes pair-by-pair all the combinations of reconstructed particles (i_1,i_2) from the block d), together with the corresponding original momenta and freeze-out coordinates generated in the block a). The value of weight is calculated, returned to the block d) and attributed to reconstructed momenta taken from the block c). In this way the influence of experimental distortions is taken into account. The background can be formed with the pairs taken from the same or different events.

f) Correlation functions. This final block is for preparation of histograms containing the correlation functions as generated by the block d).

The arrows which join the blocks a) and b) with the block d) supply undistorted data to the correlation analyzer. These data are used to construct the reference correlation functions not affected by the reconstruction procedure or by other experimental factors.

The program of simulation studies includes different physical effects measured with different hardware and software parameters of the detection system. The parameters to be tested are listed below:

– Space-time characteristics of the emitting source, e.g. r_0 = (8, 12, 16) fm;
– Type of two particle system: ($\pi^+\pi^+$), ($\pi^+\pi^-$), (π^+K^-), (π^+p), (K^-p), (pp) etc.;
– Correlation function analysis: one or three-dimensional;
– Magnetic field: B = 0.2 T, B = 0.4 T;
– Software version: e.g. two versions of tracking in the inner tracking system;
– Particle identification methods and related acceptance cuts;
– Necessary statistics for different two-particle systems, acceptance cuts etc.;
– Particular correlation effects: expansion, flow, azimuthally sensitive correlations etc.;
– Single event correlations: 2000, 6000 and 8000 charged particles per rapidity unit.

As different parameters are correlated in a rather complicated way, we will test only some combinations which seem to be essential for correlation analysis. We start from the system of two pions, perfect particle identification, and two values of magnetic field. The other parameters will be analysed successively.

As an example, the correlation function for two positive pions is presented in Fig. 6. All physical effects: QS and FSI are taken into account; the experimental resolution is included as well. The values: r_0 = 8 fm and λ = 0.5 were assumed. A systematic decrease of correlation effect is clearly seen, but is smaller if both tracking systems: TPC (time projection chamber) and ITS (inner tracking system) are included in the tracking procedure.

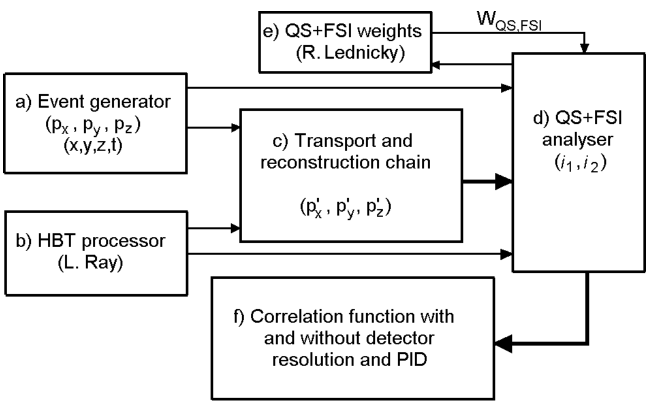

Fig. 5. A scheme of simulation chain for analysis of two-particle correlations at ALICE.

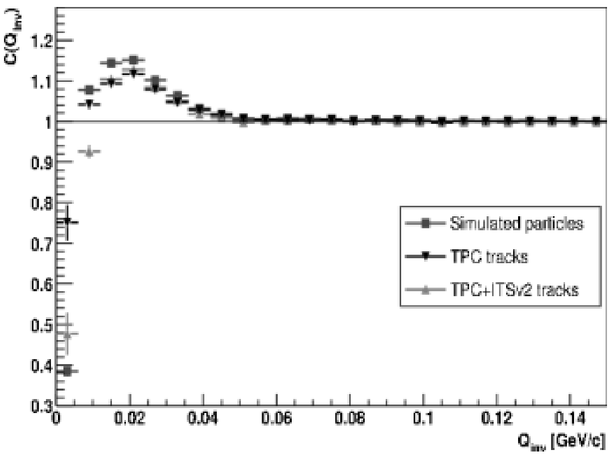

Fig. 6. Correlation function for the system of two positively charged pions emitted by the Gaussian source of r_0 = 8 fm.The intercept parameter λ = 0.5 is assumed. The results for track reconstruction by the TPC alone and by the system of TPC+ITS are presented.

The second example presents the possibilities of ALICE to construct the correlation function for pions emitted in a single event (see Fig. 7).

Such analysis is important for studies of fluctuation phenomena, but was practically impossible so far, including experiments at RHIC, due to the lack of sufficient statistics at smallest momentum differences. Not only pion multiplicity, but also the effective acceptance resulting from identification possibilities and the efficiency of track reconstruction at small relative momenta are important here. Four different values of pion multiplicities were tested. The value of dN/dY = 2000 seems to be insufficient for the construction of valuable correlation function. The larger values indicate the realistic possibilities, however.

Summary and conclusions

1. The software tools dedicated to analysis of two-particle correlations in the region of close velocities have been developed for ALICE experiment at CERN. Two approaches have been applied: 1) generation of events with the correlation effects incorporated; 2) calculation of weights attributed to the pairs of generated particles and taking into account the effects of QS and FSI.
2. The expected correlation effects shows the important role of final state interaction as a source of valuable physical information.
3. The experimental resolution affect slightly the shape of correlation function. This relatively small effect can be essential, however, for the detailed analysis in the case of negligible statistical errors.
4. For pion multiplicities dN/dY larger than 4000 at midrapidity the statistics seems to be sufficient for one dimensional analysis of pion correlations.
5. Work are in progress. The next step includes construction of the fitting procedure taking into account the Coulomb and strong FSI as a valuable physical effect (not as a correction). The correlations of: nonidentical, strange, neutral and other types of particles will be analysed as well. Some specific effects, e.g. correlations of particles coming from jets will also be considered as expected at LHC energies.

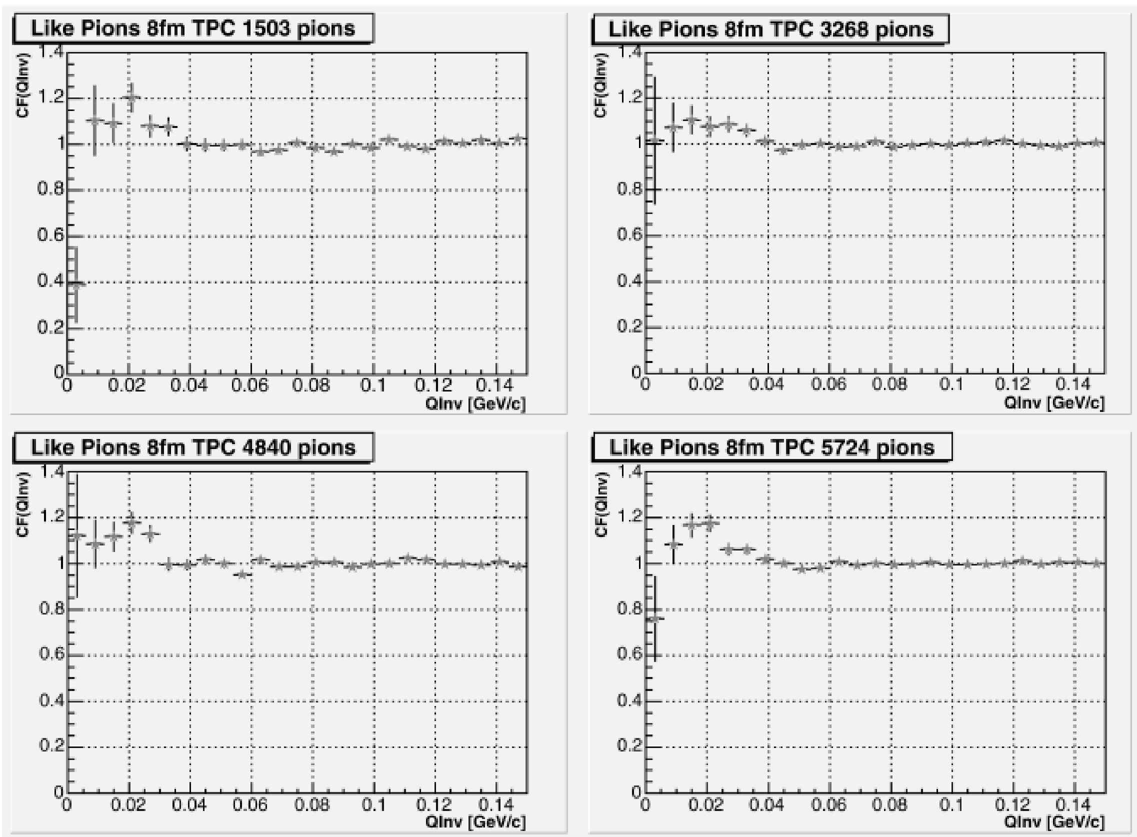

Fig. 7. Single event correlation functions for r_0 = 8 fm, λ = 0.5 and for different pion multiplicities.

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