PARTICLE CORRELATIONS WITH HEAVY IONS AT LHC ENERGIES

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The ALICE detector will offer very good conditions to study the space-time characteristics of particle production in heavy-ion collisions at LHC from measurements of the correlation function of identical and non-identical particles at small relative velocities. The correlations - induced by Coulomb and nuclear final-state interactions - of non-identical particles appear to be directly sensitive to the space-time asymmetries of particle production allowing, in particular, a measurement of the mean relative delays in particle emission at time scales as small as few fm/c.The problem of Coulomb interaction of the correlated particles is particularly important in the case of the large effective volumes formed in ultra-relativistic heavy-ion reactions.

1 Introduction

Particle correlations at high energies usually measure only a part of the space-time emission region since the sources, despite their fast longitudinal motion, emit the correlated particles with small relative velocities mainly at close space-time points.

The features of emitting sources can be investigated in the frame of an approach which includes the dynamics of the emission process as well as the effects of quantum statistics and final state, Coulomb and strong interactions. It is important that particle correlations contain information about the dynamical evolution of the emission process, such as proper time of decoupling (freeze-out) duration of particle emission and the presence of collective flows. This information is, in principle, closely related to the QGP formation [1,2,3]

2 Simulations

Our correlation analysis were performed using the string Model for Ultra-relativistic Hadronic Interactions VENUS (version 5.14) [4,5]. Based on the string model, one first determines connected regions of high energy density. These regions are referred to as quark matter (QM) droplets. For such regions, the initially produced hadrons serve only as a mean to produce the proper fluctuations in the energy density. Presently the model is not well suited for the LHC energy region. However, it provides space-time and momentum space characteristics of the freeze-out points of the emitted particles, which can be used as an approximation accounting for the basic features of the multiparticle production, including the fast longitudinal motion of the source as well as the resonance production.

The events were generated without the phase of the particle rescattering and droplet formation which normally leads to the increase of the space-time characteristics of particle emission. Instead, we introduce the scale factor which allows to extend the production region or introduce the shifts in emission times of various particle species in a controlled way.

The generation of events using VENUS model is followed by the calculation of the correlation function for the selected pairs of identical and non-identical particles. In this way we can study the sensitivity of the ALICE detector to particular correlation effects [6].

3 Experimental resolution

In order to account for effects due to the experimental resolution we used a program based on parametrisation of the full detector simulation [7]. A realistic

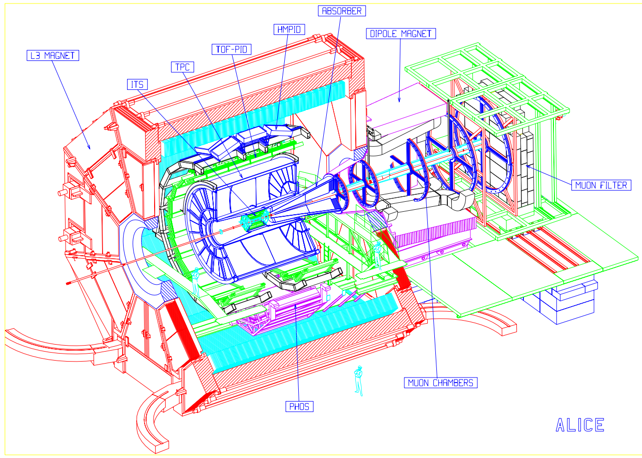

Figure 1: Alice Detector.

geometry of the ALICE central barrel has been taken into account (Fig. 1). This program does include contributions due to multiple scattering, measurement precision and detector alignment as well as fluctuations in energy loss. Effects due to the track finding algorithms were not included since the tracking efficiency in ALICE is reather good and starts only to decrease at very low transverse momentum.

The two-track resolution was not taken into account in the simulations. However, it is expected to have rather small effect on correlation functions of like particles and practically no effect on unlike particle correlations at small relative velocities. The effect of the experimental resolution on the relative momentum is summarized in Table 1.

Table 1: The ALICE resolution: $\sigma(Q_i - Q_i^{'})$, MeV/c. A cut $Q_{inv} < 0.05 GeV/c$ has been applied.

Particles	Q_{side}	Q_{out}	Q_{long}	Q_{inv}
$\pi^+\pi^+, \pi^+\pi^-$	0.3	3.8	0.7	1.2
π^+K^+, π^+K^-	0.4	4.0	1.1	1.8
π^+p, π^-p	0.4	3.9	1.3	2.0
K^+K^+, K^+K^-	0.5	6.5	2.6	3.6
K^+p, K^-p	0.6	8.2	3.2	4.8
pp	0.6	11.6	5.0	6.0

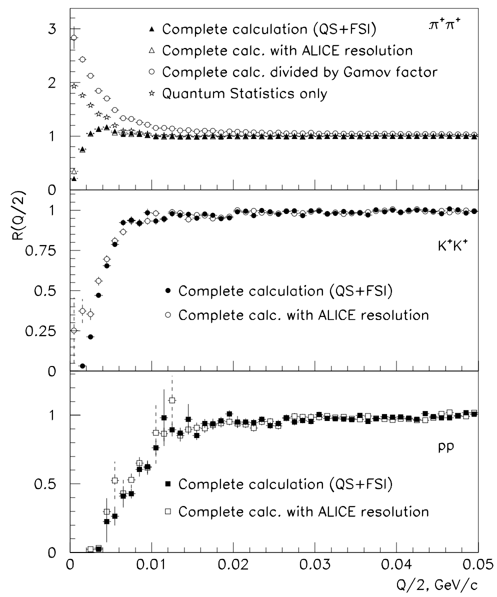

Figure 2: The simulated correlation functions for two identical charged pions, kaons and protons without and with the experimental resolution accounted for. The simulations were done using VENUS model with the extended space-time freeze-out coordinates to set $\langle r \rangle = 30$ fm and $\langle t \rangle = 20$ fm/c in the reaction c.m.s. (scale-factor = 5). For two pions the Gamow corrected correlation function is compared with that including the effect of quantum statistics only.

4 Correlation of identical particles

The correlation function of identical particles is sensitive to the relative space-time distances between the emission points due to the effects of Bose-Einstein or Fermi-Dirac statistics [8,9] and the strong and Coulomb final state interactions [10,11]. The relative importance of these three factors will be different according to the particle species.

In Fig. 2 we show the two-particle correlation functions for pions, kaons and protons calculated taking into account the effects of quantum statistics and both Coulomb and nuclear final state interactions. In the case of large effective sources, the correlations of two protons are, due to their relatively

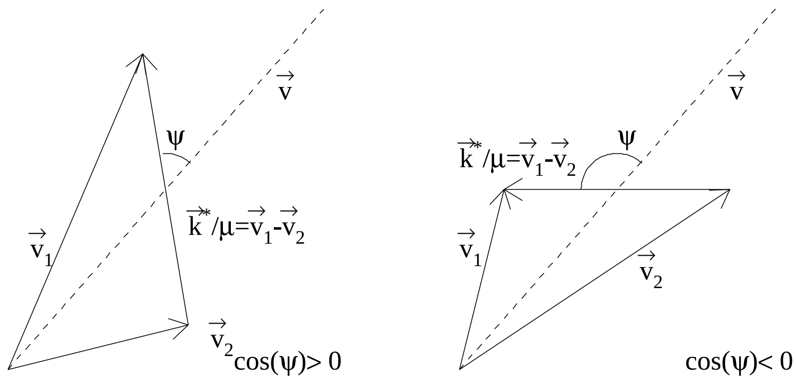

Figure 3: We can determine which sort of particles was produced earlier and which later by studying the correlation functions of two non-identical particles separately for the angles less and greater than 90° between the relative velocity $\mathbf{k}^*/\mu$ ($\mathbf{k}^* = \mathbf{p}_1^* = -\mathbf{p}_2^*$ and μ is the reduced mass of the two particles) and the total pair velocity $\mathbf{v}$.

small Bohr radius of 58 fm, stronger than those of pions and kaons. Thus, the correlations of protons appear to be a sensitive probe of the evolution of the collision in the case of large emitting region.

The correlation functions are only weakly affected by the experimental resolution even in the case of large sizes expected at LHC energies.

5 Correlations of non-identical particles

The non-identical particle correlations can be used for the determination of the space-time parameters of the emission process in a similar way as the identical ones using the sensitivity of the Coulomb and strong interaction effects to the space and time intervals of particle emissions. On the other hand, the correlations of non-identical particles appear to be directly sensitive to the sequence of particle emission [12]. To study this sensitivity one should construct the correlation functions $R_+(\mathbf{k}^*\mathbf{v} \geq 0)$ and $R_-(\mathbf{k}^*\mathbf{v} < 0)$ corresponding to the positive and negative values of $\mathbf{k}^*\mathbf{v}$, respectively (Fig. 3). On the absence of the space-time asymmetries, the ratio R_+/R_- is equal unity. In Fig. 4 we illustrate the effect of the asymmetry in the case of the emission of K^+K^- pairs. The structures (a deep or a peak) and their amplitude appearing in this ratio depend on the sign and the magnitude of the time delay introduced in

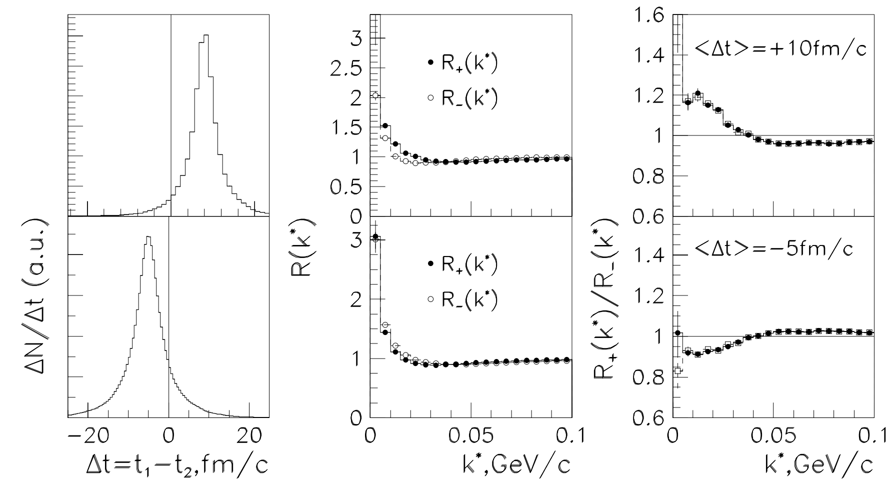

Figure 4: The distributions of the difference of the K^+ and K^- emission times $\Delta t = t_{K^+} - t_{K^-}$ simulated by VENUS with the shifts $\langle \Delta t \rangle$ =+10 and -5 fm/c introduced *ad hoc*, the corresponding correlation functions R_+ $(\mathbf{v} \cdot \mathbf{k}^* \geq 0)$ and R_- $(\mathbf{vk}^* < 0)$ and their ratios calculated for K^+K^- pairs. The ratios distorted by the effect of experimental resolution are represented by open symbols.

the calculations. The observation of a delay in the emission of K^+ and K^- can be considered, in particular, as a strong indication of strangeness distillation.

Fig. 5 demonstrates the scaling of the space-time asymmetry with the inverse Bohr radius for the like- and unlike-sign of πK, πp and Kp pairs with the corresponding Bohr radii of 248.5, 225.5 and 83.6 fm, respectively. The correlation functions for the πK, πp pairs were calculated using one simulated event only.

Due to its very good resolution, the ALICE experiment will be sensitive to the delays in the particle emission times of the order of a few fm/c even in the frame of event-by-event analysis in the case of pairs involving pions.

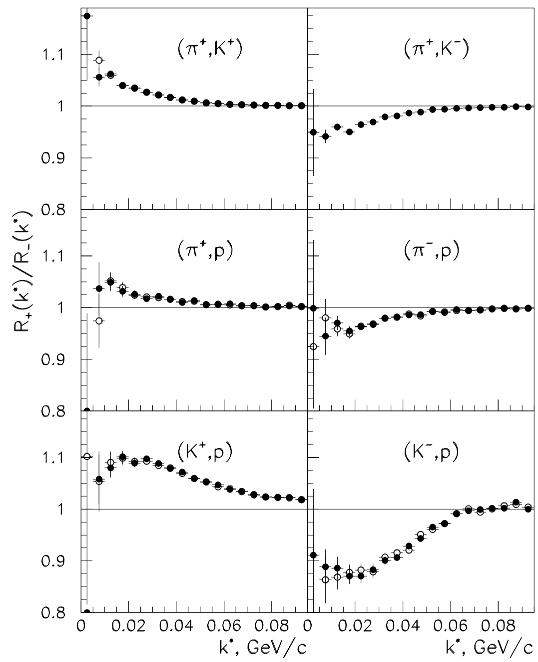

Figure 5: The same ratios R_+/R_- as in Fig. 4 calculated with $\langle \Delta t \rangle$ = -10 fm/c for different pairs of non-identical particles, taking into account (open symbols) and neglecting (full symbols) the effect of experimental resolution.

6 Coulomb corrections for interferometry analysis

For the large expanding hadron systems, expected at LHC energies, the usual Gamow correction substantially deviates from the true Coulomb effects (see Fig. 2). A simple modification of the standard zero-distance correction has been proposed [13]. This finite-size analytical Coulomb correction allows one to extract the pure quantum statistics correlation function (e.g. in a hydrodynamic model) of two identical charged pions or kaons in the case of relatively large effective emission volumes. This procedure can be useful for a fast interferometry analysis and reasonable preliminary estimate of the model parameters even at RHIC and LHC energies.

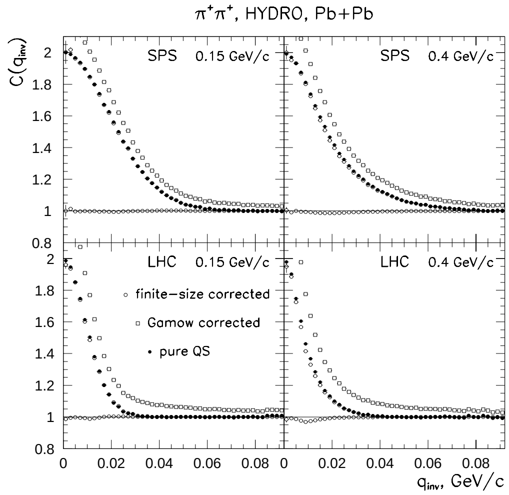

Figure 6: The comparison of the Coulomb corrected two-pion correlation functions at SPS and LHC energies for p_t=0.15 and 0.4 GeV/c, simulated with the hydrodynamical calculations. The points near the unity correspond to the ratio of the reconstructed pure quantum statistics correlation function to the finite-size corrected correlation function.

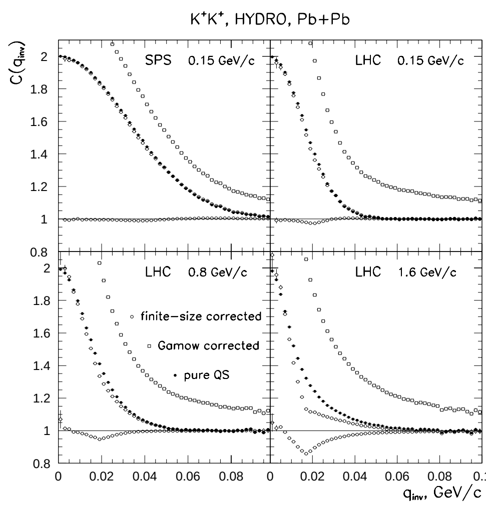

Figure 7: The same as Fig. 6 for the two-kaon correlation functions at SPS and LHC energies for p_t=0.15, 0.8 and 1.6 GeV/c.

In Figs. 6 and 7 we present the results of calculation of the pion and kaon correlation functions at SPS and LHC energies for various mean transverse momentum of the particles using the hydronynamic model [14]. The discrepancy between the pure quantum statistics calculations and the finite-size corrections appears to be significant only for kaons at high transverse momentum.

7 Conclusions

We analyzed the ability of the ALICE detector for determination of the space-time characteristics of particle production in heavy-ion collisions at LHC.

Correlation functions of various particle pairs can be measured and will be only slightly distorted by the detector resolution effects.

We demonstrated that non-identical particle correlations contain an information complementary to that provided by identical particles. In particular, the unlike particle correlations allow to determine the space-time asymmetries in the particle emission process.

The simulations of correlations of various particle pairs were performed using the event generator VENUS adapted arbitrarily for LHC conditions and including the expected resolution of the ALICE detector. The results show that the relative time delays of the order of a few fm/c can be measured.

The two-particle Coulomb interaction gives an important contribution to correlations in the case of large sizes and lifetimes. An analytical correction has been proposed allowing to extract the pure quantum statistics correlation function and to rapidly estimate the parameters describing the emitting source.

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