Calculation of predictions for non-identical particle correlations in heavy ions collisions at LHC energies from hydrodynamics-inspired models

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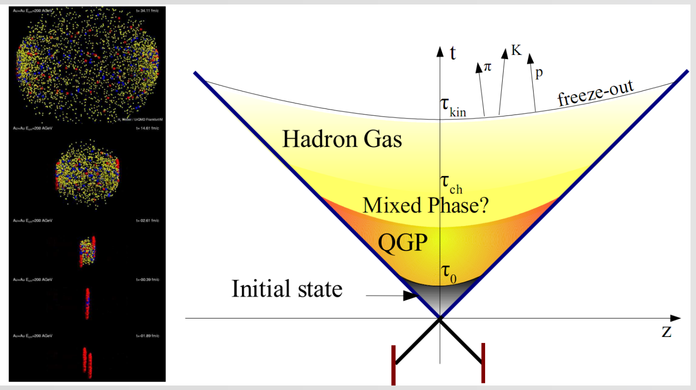
Abstract

This thesis presents results of two-particle momentum correlations analysis for different kinds of particles produced in heavy ion collisions. The studies were carried for the data from lead-lead collisions at the centre of mass energy $\sqrt{s_{NN}} = 2.76$ TeV simulated in the THERMINATOR model using the (3+1)-dimensional hydrodynamic model with viscosity. Analysis was performed for the three particle types: pions, kaons and protons for the collisions in eight different centrality ranges. Relativistic hydrodynamics predicts appearance of femtoscopic radii in the LCMS. This thesis concentrates on verification of such scaling and tests the possibility of scaling recovery in PRF.

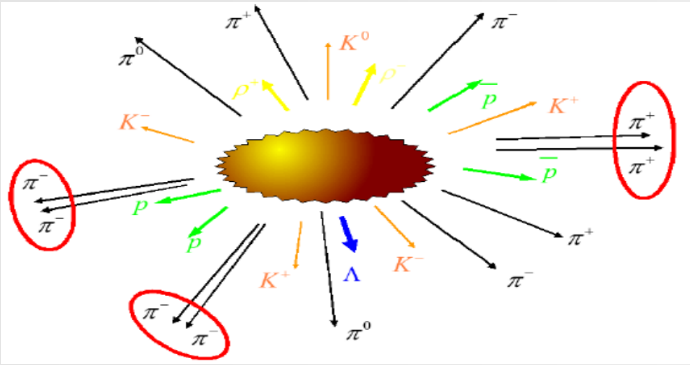
Heavy Ion Collisions

At the beginning, two thin discs are approaching to themselves nearly at the speed of light in order to collide with each other. In this reaction, energy stored in accelerated nuclei is used to investigate a strong interaction, a force which is binding nucleons into nuclei. Quantum Chromodynamics predicts an appearance of a new state of matter in relativistic heavy ion collisions - a quark-gluon plasma. Recent discoveries show, that this new state of matter behave like an ideal fluid and can be described by hydrodynamic equations.



Particle Interferometry

Two-particle interferometry (also called femtoscopy) gives a possibility to investigate space-time characteristics of the emitting source. Through the study of two-particle correlations, their momentum distributions can be used to obtain information about the extent of created system. This method allows to measure sizes of the order of 10^{-15} m and time of the order of 10^{-23} s.



THERMINATOR Model

THERMINATOR is a Monte Carlo event generator designed for studying of the statistical production of particles in relativistic heavy ion collisions. The creation of stable particles and unstable resonances (hadronisation) is determined by statistical (Bose-Einstein and Fermi-Dirac) distribution factors. After the hadronisation phase, the THERMINATOR provides space-time evolution and resonances decays in cascades. The key element of this approach is the inclusion of the complete list of hadronic short-time living resonances, which at the rather high temperature at freeze-out ($T_f \approx 165MeV$) contribute very significantly to the observed particles. This code does not take into account interactions between final state hadrons. THERMINATOR is written in C++ language and uses the CERN ROOT environment.

Calculation Method

Experimental correlation function is calculated from simulated data using following formula:

$$C(\mathbf{k}^*) = \frac{N}{D} = \frac{\sum_{n_i \in D} \delta(\mathbf{k}^*_i - \mathbf{k}^*) |\Psi_{ab}(\mathbf{r}^*_i, \mathbf{k}^*_i)|^2}{\sum_{n_i \in D} \delta(\mathbf{k}^*_i - \mathbf{k}^*)} , \quad (1)$$

where N and D are three dimensional histograms of a particle pairs relative momentum $2k^*$ and Ψ_{ab} is a pair wave function. In order to carry out multi-dimensional analysis of a correlation function, a decomposition into spherical harmonics series was performed:

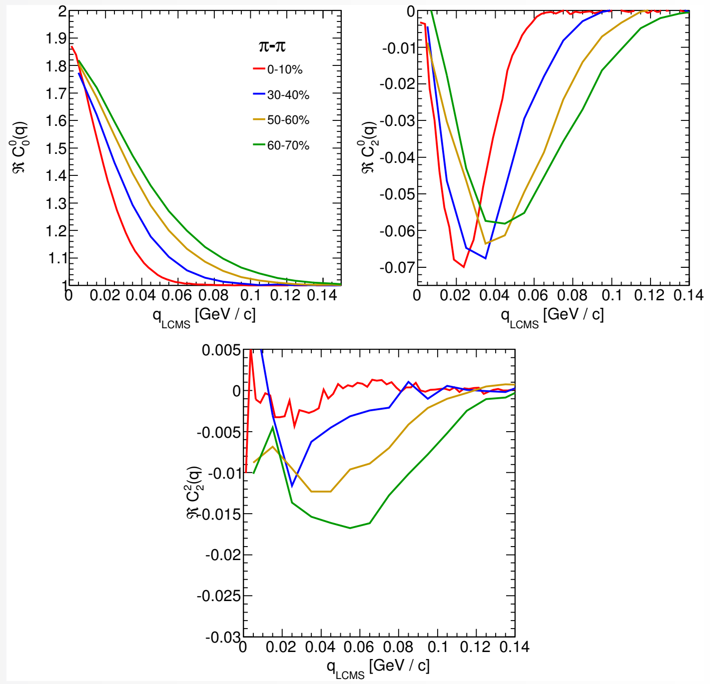
$$C(\mathbf{q}) = \sum_{l,m} C_l^m(q) Y_l^m(\theta, \phi), \quad (2)$$

$$C_l^m(q) = \int_\Omega C(q, \theta, \phi) Y_l^{m*}(\theta, \phi) d\Omega , \quad (3)$$

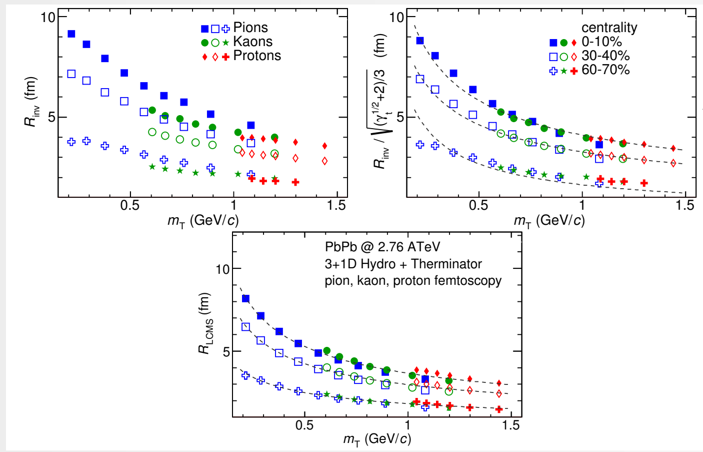
where Y_l^m is spherical harmonic, $\mathbf{q}$ is a pair momentum difference, Θ and ϕ are spherical coordinates.

Experimental Correlation Functions

The correlation functions (three- and one-dimensional) were calculated separately for the following different pairs of identical particles: π-π, K-K and p-p for nine k_T bins (in) from 0.1 GeV/c to 1.2 GeV/c. The three-dimensional correlation function as a function of relative momentum q_{LCMS} was calculated in a form of components of spherical harmonics series accordingly to Eq. 2. In the femtoscopic analysis of identical particles, the most important information is stored in the $\Re C_0^0$, $\Re C_2^0$ and $\Re C_2^2$, hence only these components were analyzed. Correlation functions obtained in this procedure were calculated for the pairs of pions, kaons and protons in the different centrality bins. Particular coefficients for pairs of identical bosons (pions and kaons) are shown in the plot on the right side. The wave function symmetrization (Bose-Einstein statistics) causes the increase of correlation in the low relative momenta regime. The $\Re C_0^0$ resembles one-dimensional correlation function in the sense that it encodes information about the overall source radius. The second coefficient $\Re C_2^0$ differs from zero (is negative), which yields the information about the ratio R_T/R_{long}. The $\Re C_2^2$ stores the information about R_{out}/R_{side} ratio and one can notice that is non-vanishing (is also negative).



Results for Radii Scaling



From identical particles correlation functions one can extract femtoscopic radii (R) - ranges of correlation effect between particles. Calculations of a correlation function can be performed in two coordinate systems: Pair Rest Frame and Longitudinally Co-moving System. Hydrodynamics predict the following rule: $R_{LCMS} = \alpha m_T^{-\gamma}$, where m_T is a transverse mass, α and γ are parameters. Plots on the right side present femtoscopic radii from PRF (upper left) and LCMS (lower one). Upper right plot present results in PRF divided by proposed scaling factor: $\left[\left(\sqrt{\gamma_t}+2\right)/3\right]^{-1/2}$, lower plots are in LCMS. One can notice that the femtoscopic radii are falling on the common curve after division.

Conclusions

Hydrodynamic equations are predicting appearance of the common scaling of femtoscopic radii for different kinds of particles with $m_T^{-0.5}$ in LCMS. In the results of this work, a common scaling for different particle types is observed in LCMS in the outward, sideward and longitudinal directions. The direction-averaged radius R_{LCMS} also shows this power-law behaviour. The fitting of a power-law $\alpha m_T^{-\beta}$ to the femtoscopic radii yielded the information that the β exponent for the outward and sideward directions is of the order of 0.5, which is consistent with the hydrodynamic predictions. For the longitudinal direction, the β is bigger (>0.7) than in the other ones, which is an indication of a strong transverse flow.

In the case of the one-dimensional radii R_{inv} calculated in PRF, no common scaling is observed. However, one can try to correct the influence of the R_{out} growth with an approximate factor $\sqrt{\left(\sqrt{\gamma_T}+2\right)/3}$. After the division of the R_{inv} by the proposed factor, the scaling is restored with an accuracy < 10%. In this way, the experimentally simpler measure of the one-dimensional radii can be used as a probe for the hydrodynamic collectivity.