MPD Performance to Femtoscopy Correlations

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1 Introduction

The momentum correlations of two or more particles at small relative momenta in their center-of-mass system are widely used to study space-time characteristics of the production processes on a level of 10^{-15} m, so serving as a correlation femtoscopy tool. Usually, it is assumed that the correlation of two particles emitted with a small relative velocity is only influenced by the effects of their mutual quantum statistics and final state interaction. The primary goal of femtoscopy, performed at mid-rapidity and low transverse momentum, is to study the space-time size of the emitting source and freeze-out processes of the dynamically evolving collision system. Our task is to analyze the performance of the combination of detectors TPC+TOF to reconstruct the femtoscopy correlations. In our analysis we take into account only quantum statistics.

2 Interferometry with identical particles.

Information about the space-time structure of the particle emission source (fireball) can be extracted by the femtoscopy or HBT interferometry analysis. The idea of this analysis is based on correlations between pair of particles with the small relative momentum. The measured Lorentz invariant two-particle distribution

$$P(p_1, p_2) = E_1 E_2 \frac{dN}{d^3p_1 d^3p_2}$$

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contains any two particle momentum correlation of the production mechanism in a heavy ion reaction. Here $P(p_1, p_2)$ indicates the probability to measure two particles with momenta p_1 and p_2. This distribution is mainly shaped by the single particle distribution. Hence the correlation function

$$C_2 \equiv \frac{P(p_1, p_2)}{P(p_1)P(p_2)}$$

is defined. The reference distribution $P(p_1)P(p_2)$ is the probability to measure two particles with momenta p_1 and p_2 derived only from single particle spectrum

$$P(p) = E\frac{dN}{d^3p}$$

The reference distribution mimics the two particle distribution except for any two particle correlation. Although it could be calculated in principle from the single particle spectrum $P(p)$, in experimental analyses usually the "mixed event method" is applied to model the background. That means, pairs defining the background distribution are constructed with particles from two different events. Since usually many events are recorded, the number of "mixed pairs" exceeds by far the number of "real pairs", i.e. all possible combinations of two particles from the same event. If the number of mixed pairs is chosen to be 10–15 times larger than the number of real pairs the statistical error of the correlation function is given mainly by the statistics of the real pairs distribution.

The indistinguishability of identical particles leads to the requirement that observables of multiparticle states must be independent of the order of the particles. The probability amplitude for bosons must be symmetric with respect to the interchange of particles. This enables us to relate the correlation function to the density

$$C_2(q) = \frac{P(p_1, p_2)}{P(p_1)P(p_2)} = 1 + |\tilde{\rho}_{eff}(q)|^2 , \tag{1}$$

where the effective density of the source is

$$\tilde{\rho}_{eff}(q) = \int dx\, e^{iqx} \rho_{eff}(x).$$

Equation (1) is the basic relation of Bose–Einstein interferometry: the measured momentum correlation function $C_2(q)$ provides information about the space-time structure of the particle emitting source.

A convenient choice for the three independent components of $\mathbf{q}$ in equation (1) is give by Podgoretskii-Pratt-Bertsch parametrization. Corresponding radii enter the correlation function as

$$C_2(\mathbf{q}, \mathbf{k}) = 1 + \lambda(\mathbf{k}) \exp(-q^2_{side} R^2_{side} - q^2_{out} R^2_{out} - q^2_{long} R^2_{long})$$

Here q_i are the components of the pair momentum difference q in the i-th (out, side, longitudinal) directions. The factor λ is the incoherence parameter that ranges from 0 (complete coherence) to 1 (complete incoherence). The speciality of the task demands good track reconstruction and good efficiency of identification of particles.

3 Track selection

Distribution of number of hits and χ^2 divided over number of hits for primary tracks path through the TPC volume are shown in Fig. (1). Fig. (2) shows detailed distribution of number of hits over pseudorapidity and transverse momentum.

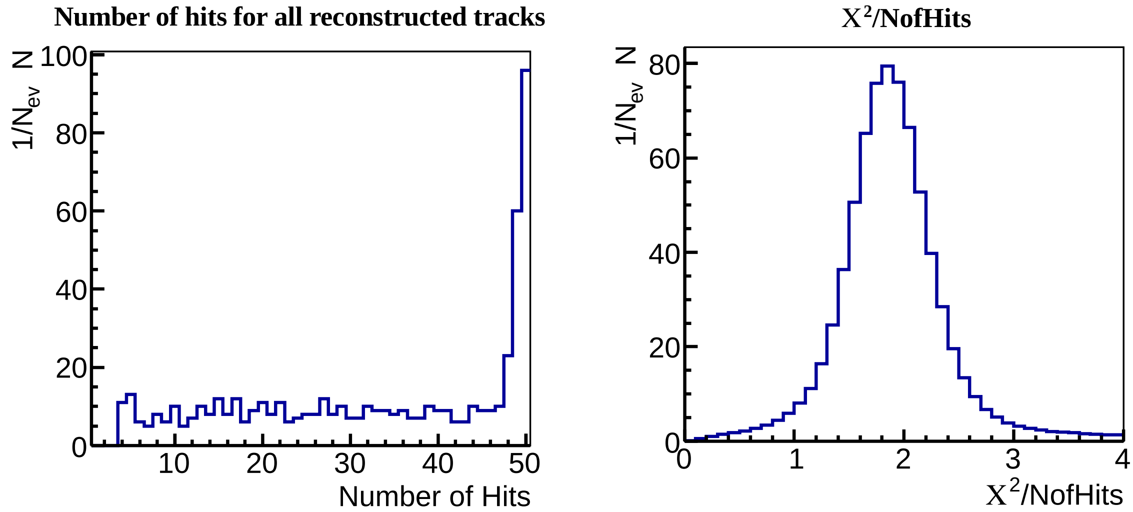

Figure 1: Distribution of number of hits (left) and χ^2 (right) for primary tracks path through the TPC.

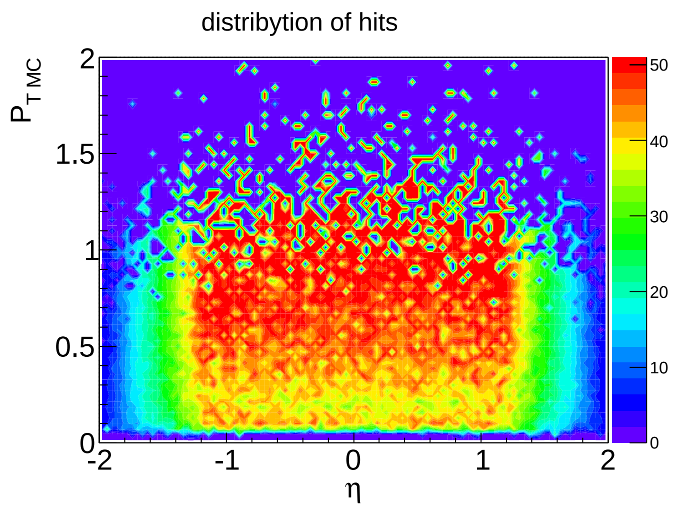

Figure 2: Distribution of number of hits (in color) with respect to pseudorapidity and transverse momentum.

For our analysis, only primary tracks which has more then 30 hits in TPC and $\chi^2/NofHits < 3$ was accepted. This provides quite good track reconstruction quality and, as one can see in fig. (2), excludes effect of edges in TPC.

4 Identification

Combined probability was used for identification of pions. It takes into account both time of flight and energy loss in the volume of detector. Combined probabilities to be pion/kaon/proton for the real pion with respect to the transverse momentum is shown in fig. (3). The level of probability to be pion was chosen equal to 0.6. The efficiency (ratio of number of identified

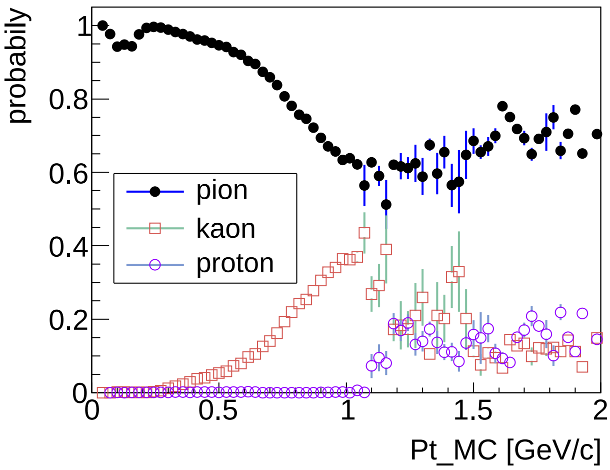

Figure 3: Combined probability of real pion to be pion/kaon/proton.

pions to number of real pions) and contamination (ratio of number of wrong identified pions to number of identified pions) of identification of charged pions with given criteria is presented in fig. 4.

The level of probability equal to 0.6 is quite strong. It gives good efficiency up to $P_T < 1\,GeV/c$, but it omits many pions with $P_T > 1\,GeV/c$ and leads to two separate regions in efficiency (see fig. (4)). Our kinematic cuts are the following: $|\eta| < 1.2$ and $0.2 < P_T < 1.5\,Gev/c$.

5 Correlation functions for identical pions

One dimensional correlation functions for identical pions ($\pi_-\pi_-$) developed after Monte–Carlo simulation of detector MPD are shown in figs. (5,6,7,8,9). The results presented here are based on 10^5 Au+Au central events at the center-of-mass energy of nucleon pair $\sqrt{s_{NN}} = 9$ GeV, which was generated by HSD transport model. Fig. (5) corresponds to the whole set of transverse momentum k_t for pair of identical pions. The others, figs. (6,7,8,9), show the dependence on the transverse momentum for pair of pions. The red solid line denote the following fit:

$$C_2(Q) = N\ \left(1 + \lambda \exp(-Q^2R^2)\right)$$

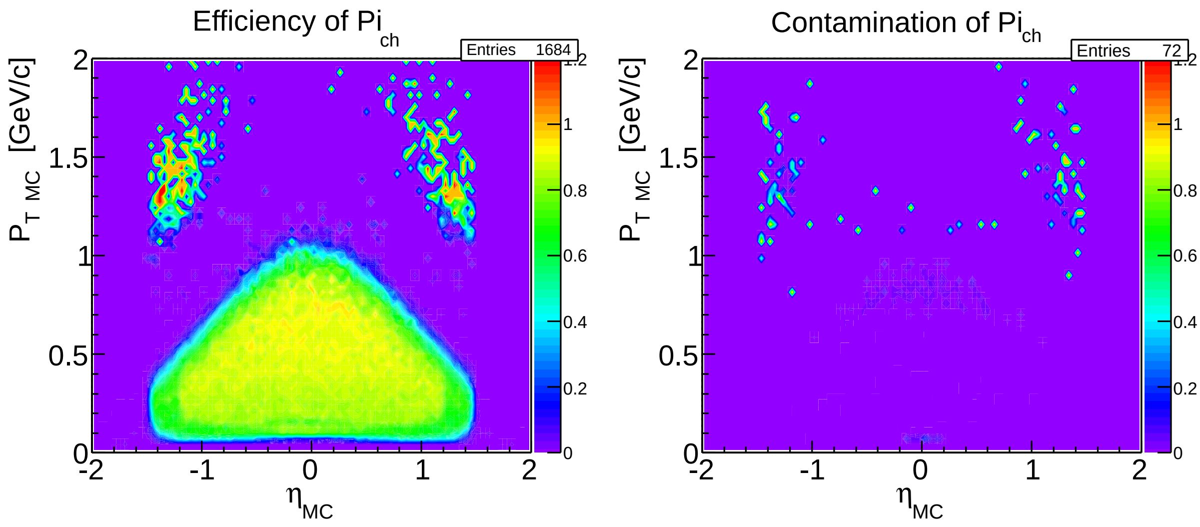

Figure 4: Efficiency and contamination of identification with given criteria.

for the correlation functions over Q_{out}, Q_{side} and Q_{long}. All of figures are normalized so that $N = 1$.

The absence of points in correlation function over Q_{out} in fig. (6) is the result of kinematic restrictions.

6 Results and comparison.

Results of fits, discussed in previous section, with respect to the model (HSD) are shown in fig. 10. Here fitting errors are smaller then size of marker. One can see good agreement in simulated values of λ, R_{out}, R_{side} with the model. At the same time, distribution of R_{long} demonstrates some systematical errors. The ratio R_{out}/R_{side}, connected with emission time of the source, is shown in fig. (11).

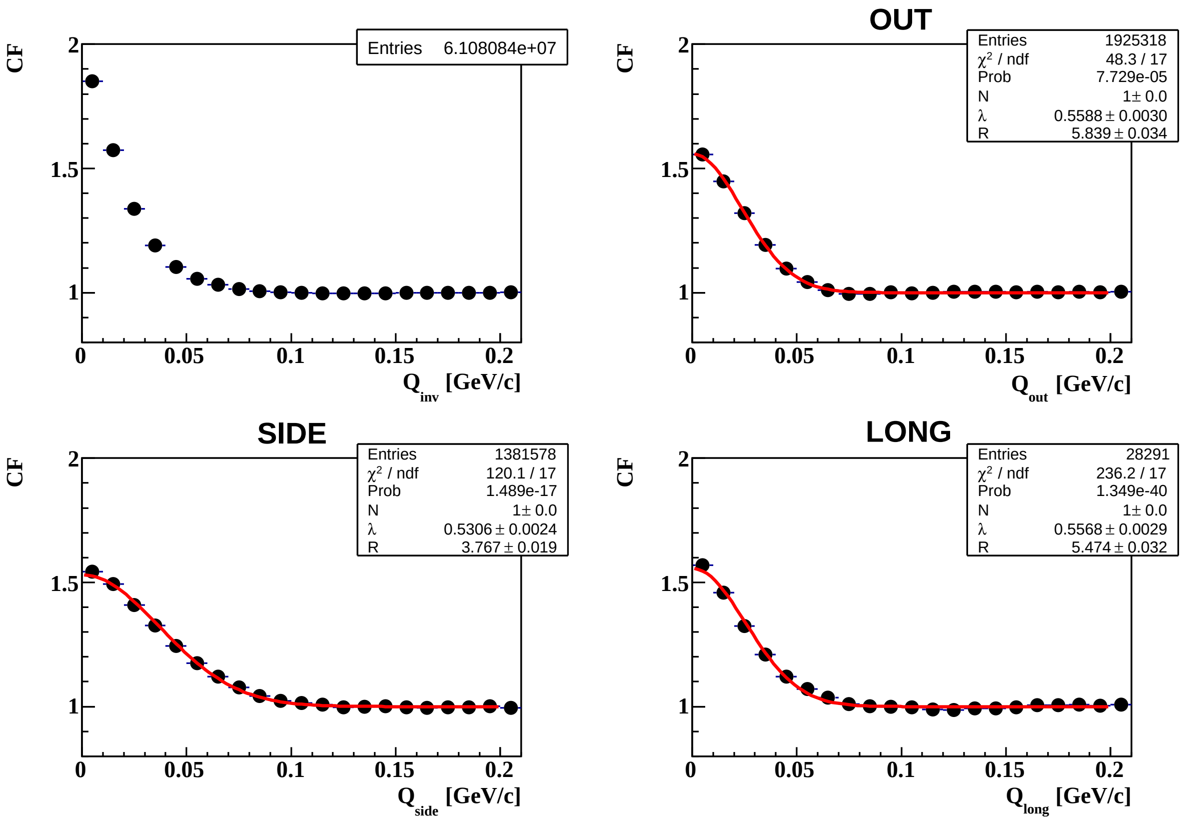

Figure 5: Correlation functions for the whole set of transverce momentum for pair of identical pions.

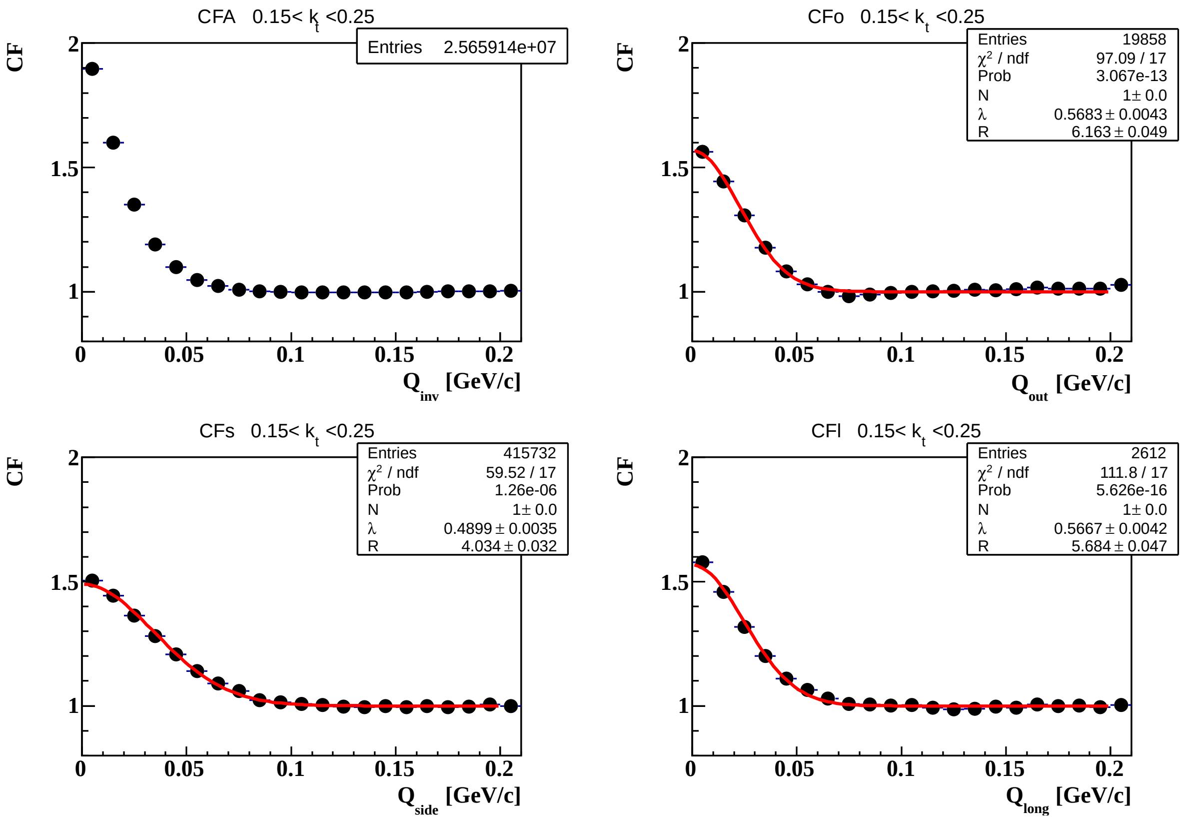

Figure 6: Correlation functions for the range of transverse momentum $0.15 < k_t < 0.25\,GeV/c$.

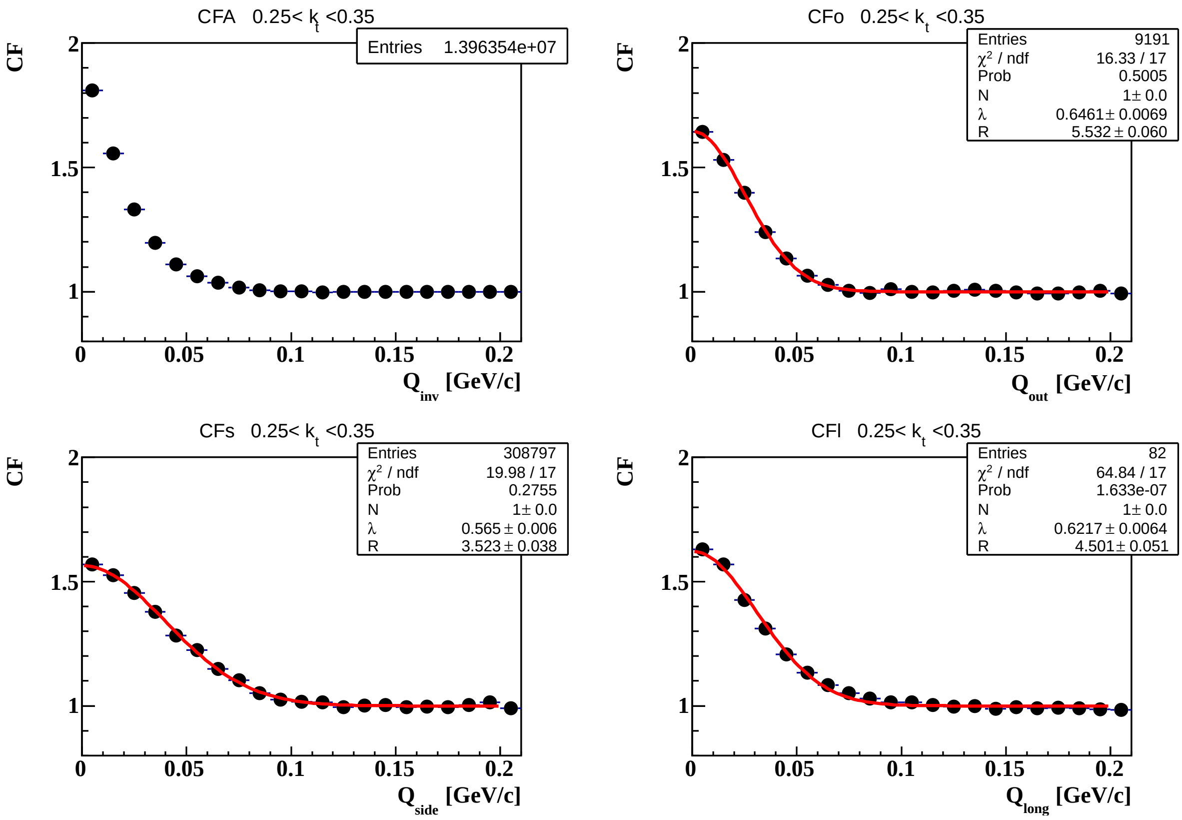

Figure 7: Correlation functions for the range of transverse momentum $0.25 < k_t < 0.35\, GeV/c$.

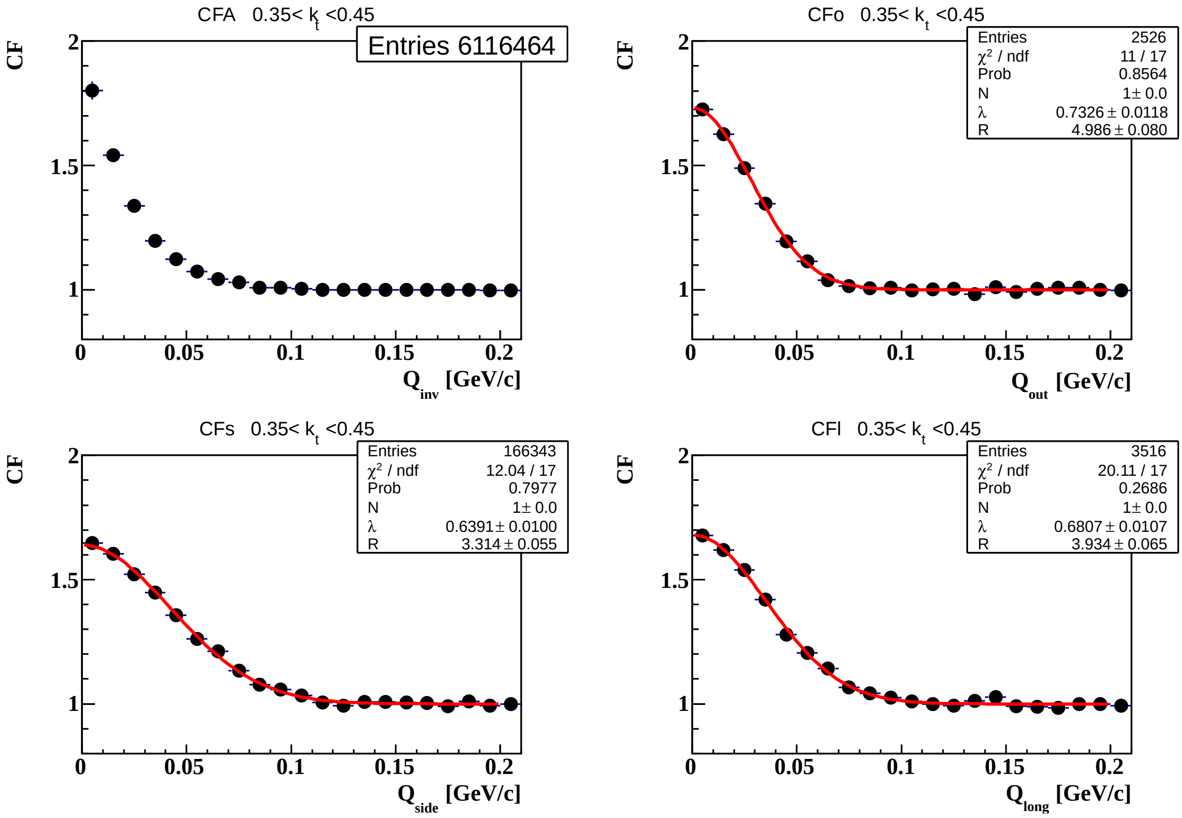

Figure 8: Correlation functions for the range of transverse momentum $0.35 < k_t < 0.45\,GeV/c$.

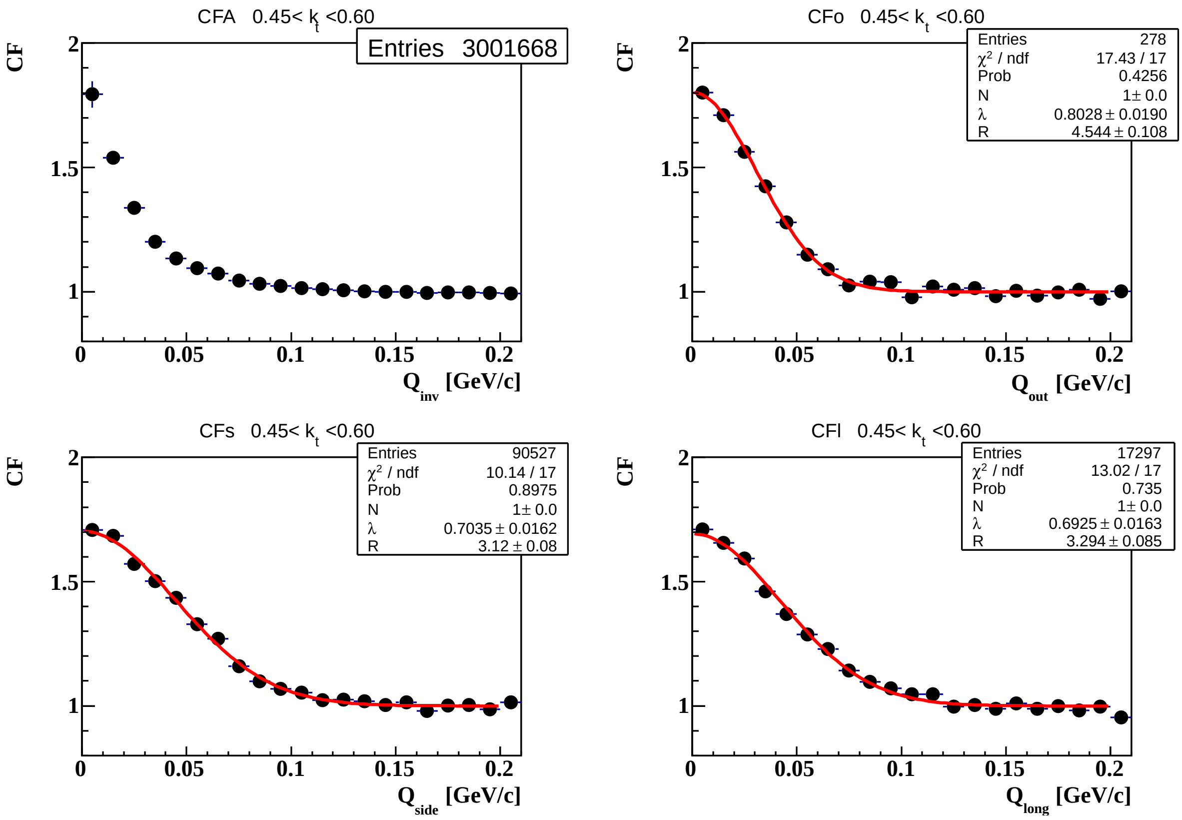

Figure 9: Correlation functions for the range of transverse momentum $0.45 < k_t < 0.60\, GeV/c$.

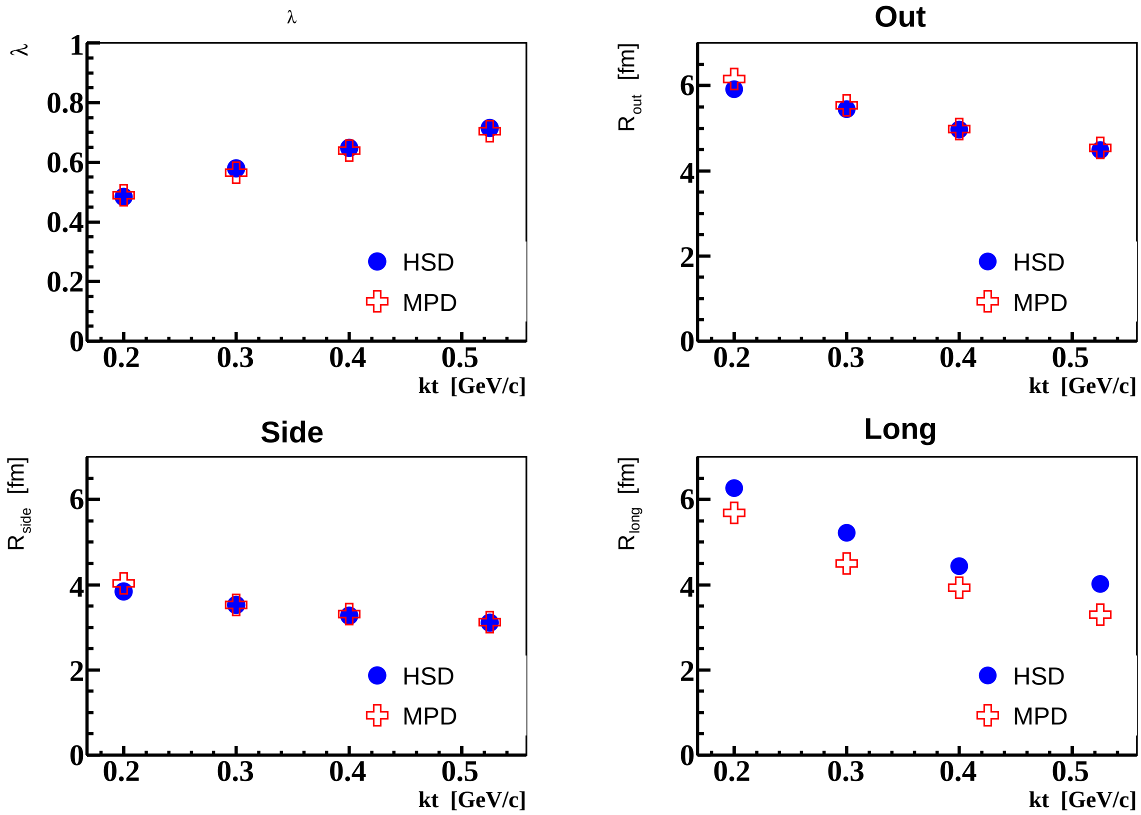

Figure 10: Comparison of simulation with the model.

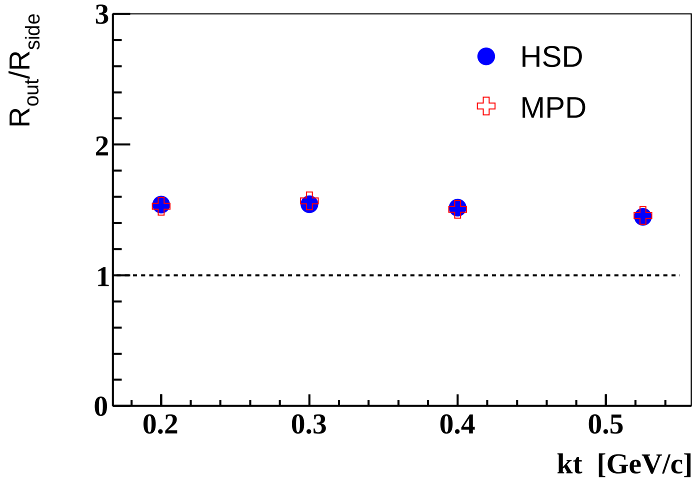

Figure 11: Comparison of simulation with the model.