Vol. 14 (2021) *Acta Physica Polonica B Proceedings Supplement* No 3

FEASIBILITY STUDIES OF FEMTOSCOPIC MEASUREMENTS IN MPD*

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(Received February 1, 2021)

Femtoscopy is one of the methods used in high-energy physics. This technique is used to measure the size of the source created as a result of heavy-ions collision. By using Monte Carlo (MC) simulations, it is possible to estimate the precision of such measurements. This paper discusses estimation of the precision of the femtoscopic measurements in the MPD experiment by using the MC data.

DOI:10.5506/APhysPolBSupp.14.507

1. Introduction

The NICA (Nuclotron-based Ion Collider fAcility) accelerator allows to perform the collisions of gold ions at the energy range of $\sqrt{s_{NN}} = 4$–11 GeV. The MPD (Multi-Purpose Detector) is one of the planned experiments at the NICA complex.

The structure of MPD is very similar to the structure of ALICE and STAR detectors [1–3]. All those experiments use the TPC (Time Projection Chamber) detector as the main tool for tracking, TOF (Time Of Flight) is used to improve identification of particles registered by TPC.

Femtoscopic analyses require precise measurements of identified particles with small relative momenta. ALICE and STAR collaborations studied the impact of the limited detector performance on such measurements. Additional criteria of pair selection were used to remove (or at least reduce) splitting (reconstruction of a particle incorrectly as a pair of trajectories) and merging (reconstruction of pair of particles as a single trajectory) effects [4]. Procedures used by both collaborations were used in this work.

* Presented at NICA Days 2019 and IV MPD Collaboration Meeting, Warsaw, Poland, October 21–25, 2019.

2. Femtoscopy

Femtoscopy uses correlations between particles to measure the size of the source that emits particles. There are two sources of these correlations: Quantum Statistical (QS) effects and Final State Interactions (FSI). The main tool of femtoscopy is Correlation Function (CF). The measured correlation function is usually fitted by the following formula:

$$\mathrm{CF}(q) = N(1 + R(q,R))\,. \tag{1}$$

In (1), factor N represents the normalization factor. $R(q,R)$ describes the part of function that is defined by two-particle correlations and interactions — it carries information about the size of the measured source [5]. For the Gaussian source and pairs of identical, non-interacting pions, the $R(q,R)$ is equal to $\lambda \mathrm{e}^{-q^2R^2}$, where λ is a fraction of correlated pairs, and R is the radius of the source. In experiment, the shape of the function might be modified by detector effects.

3. Data and data selection

To estimate the precision of measurements in MPD, the MC data were used. The first step was to generate the sample of the central Au+Au collisions in UrQMD at $\sqrt{s_{NN}} = 11$ GeV. These data were used to simulate the response of the detector by using the MPDRoot framework. NicaFemto package was used to analyze data. Approximately 3.5 million events with centrality 0–5% were analyzed. It was required that collisions always took place in the center of the detector.

The criteria of data selection are presented in Table I. Information about ionization energy loss ($n_{\sigma\pi}$ cut) in TPC was used to identify particles with momentum smaller than 0.5 GeV/c, for particles with larger momentum, an additional cut is used (m^2_{TOF}).

Three pair cuts were used. The first cut is Fraction of Shared Hits (FSH) in TPC detector. The second cut is defined as $\Delta\mathrm{DCA}_Z = |\mathrm{DCA}_{Z1} - \mathrm{DCA}_{Z2}|$, where DCA_Z is Z-component of the Distance of Closest Approach (for the first and second particle respectively). The $\Delta\mathrm{TCP}_{\mathrm{ENT}}$ is a distance between trajectories of particles entering the TPC detector. For optimization of cuts, CF without femtoscopic correlations was used. Such a function after normalization should be equal to one (this is the shape of the CF calculated directly from the UrQMD model). Data without any pair cuts show the presence of a strong merging effect. Pair cuts were used to remove merging and splitting. However, after using such optimized pair cuts, CF still is not flat, this problem is visible in Fig. 1, where C_{BCKG} represents CF without femtoscopic correlations. Further studies show that the increased value of the CF is not a splitting effect. The "non-flatness" of the CF is stronger for pairs with larger transverse momentum.

TABLE I

Cuts used in the analysis.

Particle cuts	
$n_{\sigma\pi}$	≤ 2 cm
$N_{\mathrm{TPC\ HITS}}$	≥ 30
DCA_{XY}	≤ 1.25 cm
DCA_{Z}	≤ 0.75 cm
m^2_{TOF}	-0.3–0.15 GeV$^2/c^4$
Pair cuts	
FSH	0
$\Delta\mathrm{DCA}_Z$	≤ 0–0.4 cm
$\Delta\mathrm{TCP}_{\mathrm{ENT}}$	≥ 2 cm

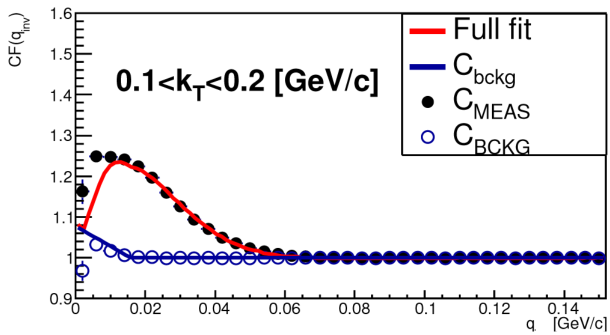

Fig. 1. (Color online) Correlation function (black) with fit (gray/red). Open circles represent CF without femtoscopic correlations. It can be noticed that the "background function" (dark gray/blue) does not describe well detector effects (open circles).

3.1. Femtoscopic analysis

One-dimensional CFs of positive pions were analyzed. The two-particle detector's effects were taken into account by multiplication of the fitting function by "background function" (F_{BCKG} in Fig. 1).

In simulations, it was assumed that the source has the three-dimensional Gaussian shape [5], parameters of this shape were taken from most central STAR data at $\sqrt{s_{NN}} = 11.5$ GeV [4]. Statistical uncertainties were negligible. The one-dimensional function was fitted by using the model function from MC. The main source of uncertainties were: background correction and fit range. Since only central events with fixed vertex were analyzed, contribution of event cuts to the systematic uncertainties was not estimated. Uncertainties are listed in Table II.

TABLE II

Systematic uncertainties of femtoscopic measurements. The first value corresponds to $0.1 < k_{\mathrm{T}} < 0.2$ GeV/c, second to $0.4 < k_{\mathrm{T}} < 1$ GeV/c.

Uncertainty source	$\Delta R\%$	$\Delta\lambda\%$
Particle identification	0.04–1.70	3.24–7.38
Momentum resolution	1.63–1.70	5.31–2.72
Fit range	3.04–8.32	2.33–9.46
Background correction	5.06–5.76	16.69–57.56
Track, pair cuts	1.06–5.09	7.02–23.27
Total (quad. sum)	6.21–48.85	19.29–63.29

3.2. Summary

The estimation of the precision of the femtoscopic measurements of pions in MPD was presented. Further studies require taking into account uncertainties related to event selection. This work also shows that there is a problem with reconstruction of particles with relatively small momenta that cannot be removed by cuts typically used in such detectors. This problem requires further studies. The analysis used data generated by relatively old algorithms from 2018, there are plans to use newer algorithms with a larger data sample. The framework for analysis was tested, currently, the development of NicaFemto is focused on fitting three-dimensional correlation functions.

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