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HADRON AZIMUTHAL CORRELATIONS TO BE STUDIED AT CBM SETUP

Поздняков В., Вертоградова Ю. E1-2008-180
Изучение азимутальных корреляций адронов на установке CBM

Рассматривается возможность изучения азимутальных корреляций адронов на экспериментальной установке CBM (ГСИ, Германия). Результаты включают детальное моделирование полученных с помощью генератора UrQMD событий и упрощенное моделирование калориметра «малых углов». Представлен ожидаемый эффект корреляций. Определение «центральности» событий ион-ионных взаимодействий проводится на основании множественности заряженных частиц, зарегистрированных в трековой системе установки, и энерговыделения в калориметре «малых углов». Различные варианты сегментации калориметра рассматриваются с точки зрения точности восстановления плоскости ион-ионной реакции.

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Hadron Azimuthal Correlations to Be Studied at CBM Setup

An opportunity of studying hadron azimuthal correlations with the CBM detector (GSI, Germany) is considered. The results include the full simulation of the UrQMD events together with a simplified consideration of the calorimeter near the beam-pipe. The expectations of the correlations are presented. The centrality determination is considered via both the charged particles detected in the tracking system and the energy deposited in the calorimeter. The segmentation of the calorimeter is discussed from the point of view of the determination accuracy of the reaction plane.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energy Physics, JINR.

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The analysis of collective phenomena in heavy-ion interactions can be used to constrain the equation of state of the nuclear matter [1]. The spacial anisotropy of interacted volumes of nuclei (Fig. 1) formed in mid-central collisions and scattering of produced particles during the system evolution both convert to the spacial hadron anisotropy with respect to the so-called «reaction plane». The latter is determined by the axis of the ion collisions and by a line of an impact parameter. Observation of this in-plane transverse collective motion («flow») can be interpreted as hydrodynamical effects in the compressed nuclear matter [2].

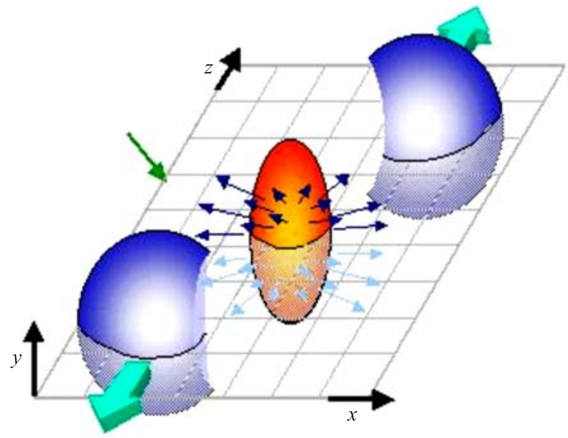


Fig. 1. Illustration of nucleon–nucleon interaction

The study of the flow(s) suggests that there are possibilities in the experiment environment to select the events within a range of the centrality and to determine the reaction plane position as accurate as possible. Since the azimuthal correlations (AC) are expected to be different for various spices of the produced particles, it is desirable to have a possibility to identify particles or reconstruct the short-lived ones. The CBM setup [3], designed to investigate the compressed baryonic matter in the fixed-target environment with FAIR facility [4], meets these requirements. The setup will include a high-precision tracking system (based on silicon detectors) and a forward calorimeter to register projectile spectators (a lead/scintillator sandwich compensating calorimeter). The both detectors are the main devices to determine the centrality and reconstruct the reaction plane, too. The TOF system (based on the Resistive Plate (RP) chamber technology) of the CBM setup will allow one to separate $\pi/K/p$.

The event simulation has been done with the UrQMD event generator [5] and GEANT package [6] for the particle transport through the setup. The event reconstruction is made by different types of algorithms [3] implemented into CBM software. The theoretical model of the UrQMD generator incorporates different heavy-ion reaction mechanisms that brings to yield observables. The simulation was done for AuAu ion collisions at the beam energy of 25 GeV per nucleon for the present study.

The Fourier decomposition of the azimuthal distributions of the produced particles with respect to the reaction plane, brings to the flow components expressed in terms of the Fourier coefficients [7]:

$$dN/d(\phi_{\text{particle}} - \phi_{\text{reaction-plane}}) \sim \sum v_i \cos[i\,(\phi_{\text{particle}} - \phi_{\text{reaction-plane}})], \quad (1)$$

where the variables

$$v_i \equiv < \cos[i(\phi_{\text{particle}} - \phi_{\text{reaction-plane}})] > \quad (2)$$

are called by the directed ($i = 1$) and elliptic ($i = 2$) flows.

It is worth mentioning that the azimuthal correlations are inside of the event generator with the reaction plane oriented along the x axis, i.e., the azimuthal angle of the plane is fixed at zero angle. This allows one to verify expectations for AC. Figure 2 presents variables v_1 and v_2 for different particle spices and for three domains of the impact parameter b (which correlates with the centrality) — from the peripheral (from 8 to 12 fm of the impact parameter, filled circles) via mid-central (from 4 to 8 fm, open circles) to central (b is below 4 fm, stars) events. The expected signal coming from AC lies on the level up to 10%.

The analysis presented below was performed with the simulation of twenty thousand events of the CBM central production. The minimum bias events were generated with the UrQMD model at 25 GeV beam energy according to the bdb impact parameter distribution shown in Fig. 3. This sample does not include the simulation of the forward hadron calorimeter and that is why the same events were directed through the simplified simulation of the Projectile Spectator Detector (PSD). The detector was considered as a ring with the radius of 60 cm. The detector was located at 15 m from the interaction point (target). A particle entered PSD was considered to be fully absorbed in the detector providing a detector response for this particle. The illustration of the PSD calorimeter is presented in Fig. 4 for the $R\phi$ view. Such a simplified consideration will allow us to calculate the experimental reaction plane resolution as a function of different $R\phi$ segmentations of the detector. The inner ring in Fig. 4 shows the hole of the beam-pipe. The solid lines correspond to a division of PSD into a number of «cells» while the dashed lines show a possible (not used for the moment) shift

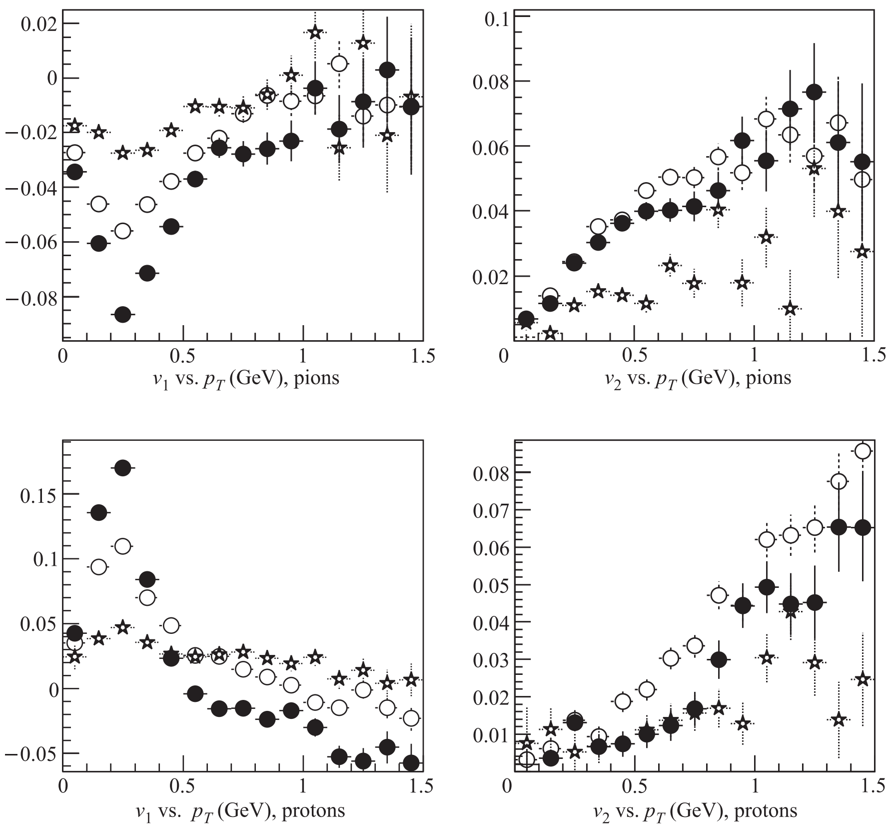


Fig. 2. Directed flow v_1 and elliptic flow v_2 for pions and protons as a function of particle transverse momentum p_T. The plots are obtained with the UrQMD event generator

of the PSD splitting along the beam to reach a better hermeticity. The cell center (see below) is set to its middle azimuthal angle.

Two variables used to determine the centrality are as follows: the number of the charged particles (charged multiplicity) reconstructed in the Silicon Tracking System (STS) [3] and the total energy deposition in PSD. The latter uses the energies of the particles entered into PSD with the energy resolution of $50\%\sqrt{E}$ applied, where E is the energy deposited in the cell. Figure 5 illustrates the x-coordinate distribution of neutrons (left histogram) and protons (right) detected in PSD. The detector is centered at x equal to 8.9 cm (the bending of charged particles occurs in $x-z$ plane) for 25 GeV beam ions passing.

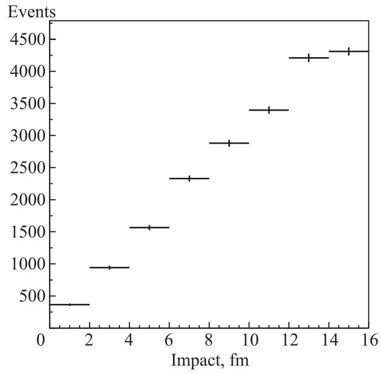


Fig. 3. The impact parameter b distribution of the simulated events

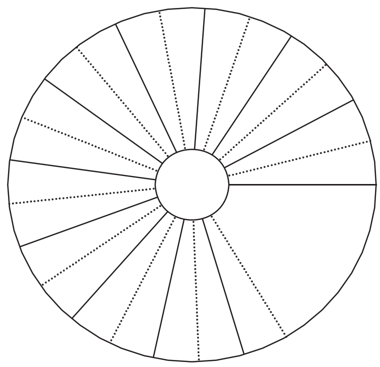


Fig. 4. The geometry of the Projectile Spectator Detector (PSD) used for the detector simulation

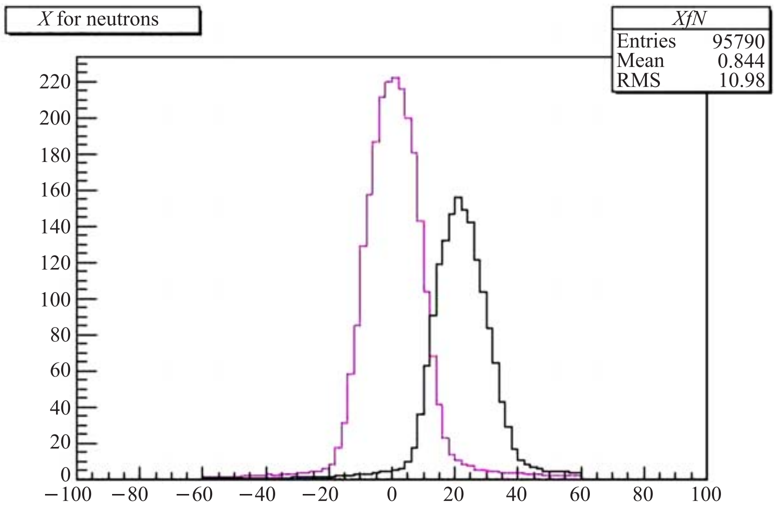
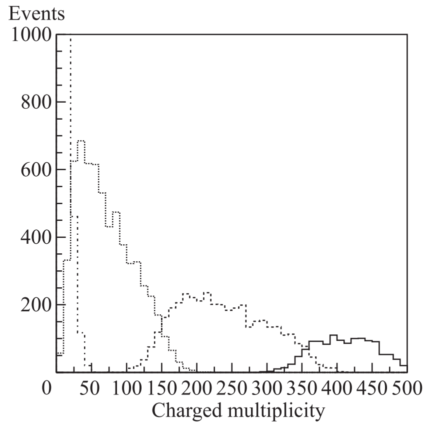


Fig. 5. The distributions of the x coordinate for neutrons (left histogram) and protons (right histogram)

The charged multiplicity accounts the particles with the momentum greater than 1 GeV reconstructed in STS. The choice of the minimum of the particle momentum is caused by two reasons — to minimize fluctuations coming from soft particles and to get high reconstruction efficiency (more than 95% [3]) for charged particles. The distributions of the charged multiplicity and the energy deposited in PSD are shown in Fig. 6 (the histograms from left to right correspond to the following impact parameter domains: greater than 12 fm, from 8 to 12 fm,



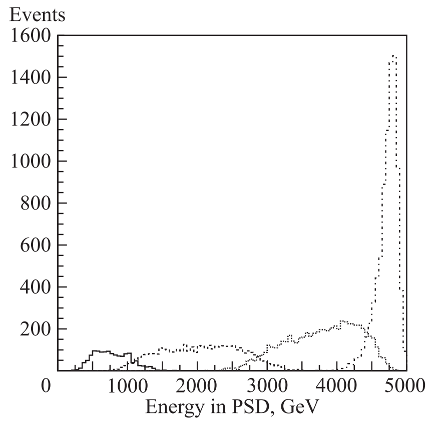
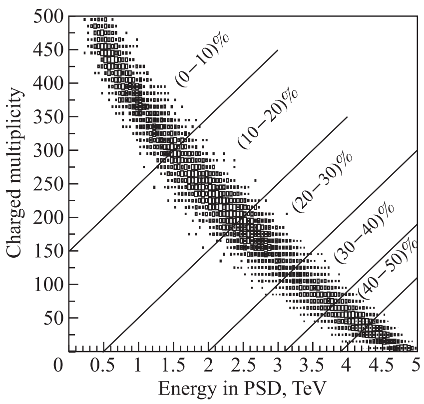


Fig. 6. The charged multiplicity in STS as a function of the impact parameter b of ion collisions

Fig. 7. The energy deposition in PSD as a function of the impact parameter b of ion collisions

from 4 to 8 fm and below 4 fm) and in Fig. 7 (the order of histograms is inverse to Fig. 6), respectively. The tendency is seen as it is expected — the rise of the charged multiplicity for more central events is accompanied by the decrease of the energy deposited in PSD.



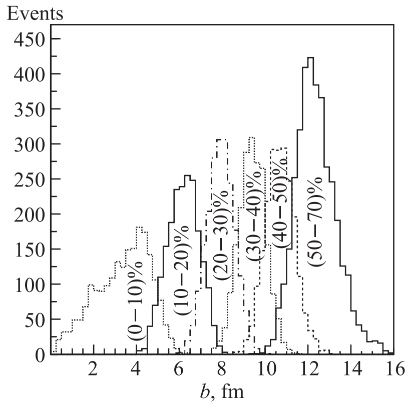


Fig. 8. The distribution of the multiplicity of charged particles reconstructed in STS vs. the energy deposited in PSD

Fig. 9. The distribution of the impact parameters for events from different centrality domains

A more significant point is the correlation between these two variables shown in Fig. 8. Their combined analysis allows one to determine the centrality domains which are calculated as a percentage of the total cross section of ion–ion interactions. The events, whose variables are located above inclined upper line, correspond to the centrality domain below 10%. The separation of events according to their centrality domains is shown by the inclined lines together with the corresponding values of the centralities.

The distribution of the impact parameter b of the ion–ion collisions corresponding to different domains of the centrality is shown in Fig. 9. The regions of interest of the task to extract the azimuthal correlations are mid-central events, in particular, the events within the impact parameter around 6 and 11 fm. The expected behavior of the directed and elliptic flows is shown in Fig. 10 for pions and protons for two mid-centrality regions. The filled (open) circles show the flows for the impact parameter domain from 5 (9.5) to 7 (11.5) fm.

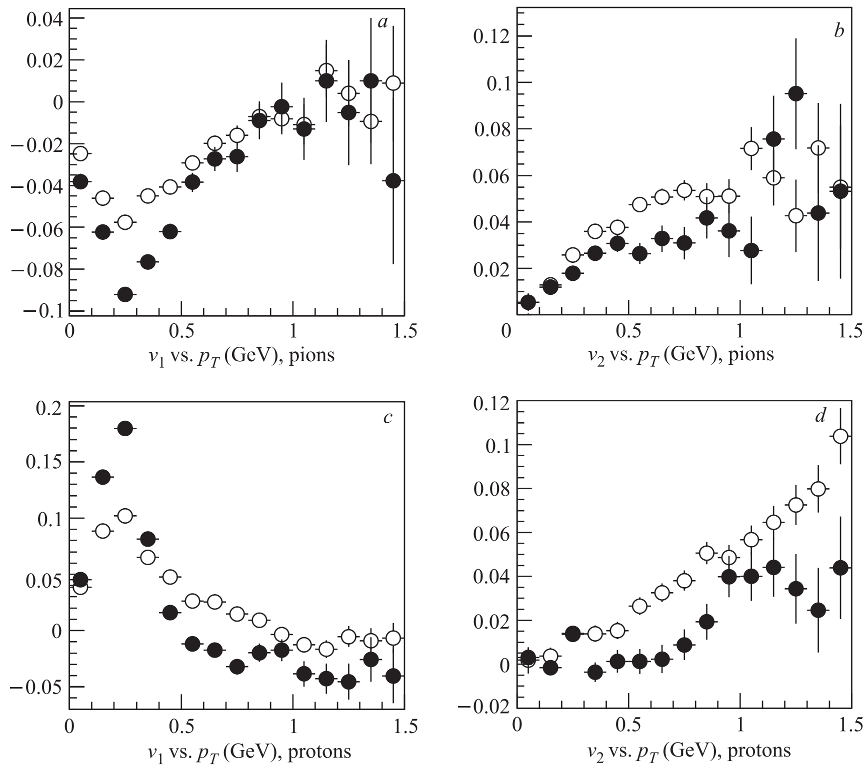


Fig. 10. Directed flow v_1 and elliptic flow v_2 for pions and protons as a function of particle transverse momentum p_T for the impact parameter b domains marked in the plot

The next part of the azimuthal correlation task is to calculate the accuracy (resolution) of the reaction plane reconstruction. To avoid overloading of the text by the terms «true» and «reconstructed» reaction planes, other terms are usually introduced. The term «reaction plane» (RP) will correspond to the true plane of an event while the «event plane» (EP) denotes an experimental (reconstructed) estimator of the reaction plane. The main device to reconstruct the event plane is PSD calorimeter*. As is mentioned above, we manipulate the PSD segmentation in $R\phi$ plane. Each segment (the part of PSD between any two solid lines in Fig. 4) will be cited as a «PSD cell». The start point is a «perfect» segmentation when each particle, entered PSD, forms its own «cell». This case will set the upper limit for the accuracy of EP reconstruction. The calculation of the EP azimuthal angle for nth harmonic ($n = 1$, 2 for directed and elliptic flows, respectively) is carried out according to the following formula:

$$\phi_{\mathrm{EP},n} = \frac{1}{\mathrm{n}}\tan^{-1}\frac{\sum E_{T,\mathrm{cell}}\sin(n\phi_{\mathrm{cell}})}{\sum E_{T,\mathrm{cell}}\cos(n\phi_{\mathrm{cell}})}, \tag{3}$$

where the summation is performed over «cells» and ϕ_{cell} means the azimuthal angle of the «cell» center in the $R\phi$ plane.

Figures 11 and 12 represent the difference between the azimuthal angles of the reaction plane and the event plane. The results are shown for three PSD segmentations — 3 (120° each, «diamond» histogram), 10 (open circles) and 17 (filled circles) segments. The results are presented for the both v_1 and v_2 variables. It is clear that the difference between 10 and 17 segments is not crucial.

Now we have reached the final step of the current study — to calculate correction factors, to reconstruct v_n. The relationship between the variable measured in the experiment and the true one looks like

$$v_{n,\mathrm{meas}} = v_{n,\mathrm{true}} < \cos[n(\phi_{\mathrm{EP}} - \phi_{\mathrm{RP}})] >, \tag{4}$$

where the last term (cosine) means the correction factor. Below we present the correction factors as a function of several segmentations for the selected impact parameter b domain of ion–ion collisions and as a function of the impact parameter for some selected segmentations. Remind that the segmentation is carried out in the $R\phi$ plane as it is drawn in Fig. 4.

The EP resolution for the events with the impact parameter between 5 and 7 fm is presented in the Table. The «Perfect» means that each particle «forms» its own PSD «cell» to be used in Eq. (3).

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*The answer to the question: Can the accuracy of RP be improved by using the charged particles registered in STS, requires further investigations.

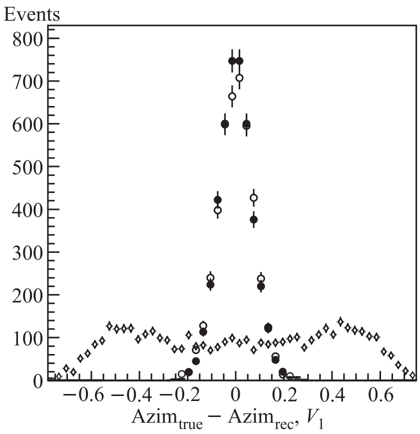

Fig. 11. Difference between azimuthal angles of the reaction plane and the event plane, as calculated for $n = 1$ (Eq. (3)), for 3, 10 and 17 PSD segments shown by «diamond», open and filled circles, respectively

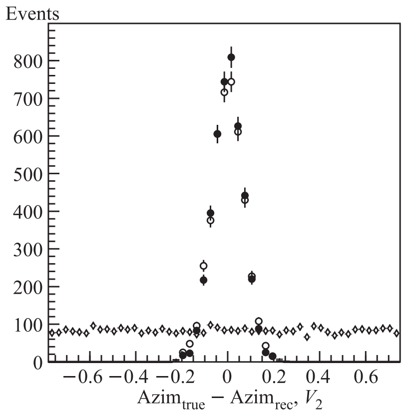

Fig. 12. The same as in Fig. 11 but for $n = 2$

The event plane resolution for different PSD segmentations

Number of «cells»	v_1 EP resolution	v_2 EP resolution
«Perfect»	$0.99^{+0.003}_{-0.01}$	$0.97^{+0.01}_{-0.05}$
3	$0.95^{+0.01}_{-0.05}$	$0.61^{+0.14}_{-0.31}$
5	$0.98^{+0.01}_{-0.03}$	$0.75^{+0.09}_{-0.21}$
7	$0.98^{+0.01}_{-0.02}$	$0.82^{+0.07}_{-0.21}$
11	–/–	$0.89^{+0.04}_{-0.14}$
13	–/–	$0.91^{+0.03}_{-0.13}$
17	–/–	$0.93^{+0.03}_{-0.10}$

Figures 13 and 14 show the dependence of $< \cos[n(\phi_{\rm EP} - \phi_{\rm RP})] >$ against the impact parameter for the three selected PSD segmentations. As is seen from the figures there is a small improvement in the RP resolution when the number of PSD cells becomes more than 10 segments.

In conclusion, the CBM setup in the present configuration is rather suitable to study the azimuthal correlations. The analysis of the information from the zero degree calorimeter PSD together with the charged particles reconstructed in STS allows one to select events in the middle centrality (impact parameters)

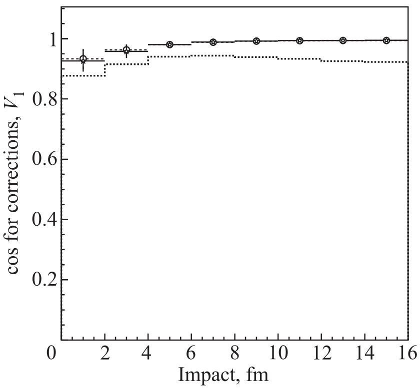

Fig. 13. Value of $< \cos[\phi_{\rm EP} - \phi_{\rm RP}] >$ as a function of the ion–ion impact parameter for 3 (histogram), 10 (open circle) and 17 (stars) PSD segmentations

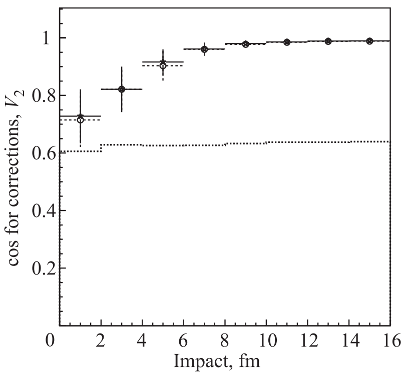

Fig. 14. The same as in Fig. 13 but for $< \cos[2 \cdot (\phi_{\rm EP} - \phi_{\rm RP})] >$

of collisions. The segmentation of PSD on more than 10 parts will allow one to reconstruct the reaction plane of ion–ion collisions with rather high accuracy. The following steps should include: consideration of other (according to the existing technology of PSD construction) shapes of PSD to compare them with the ones presented in this study; a detailed simulation of PSD; additional other beam energies; study of selected spices (kaons and D mesons) with respect to the reaction plane.

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