MPD Collaboration

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Event Centrality Determination and Reaction Plane Reconstruction at MPD

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1 Introduction

In noncentral heavy ion collisions the initial anisotropy of the interaction zone results in the azimuthal anisotropy of emitting particles in momentum space. This anisotropy is counted with relation to the reaction plane defined by the beam direction and the vector of the impact parameter. The reaction plane can be reconstructed only if the final state of the interaction products retains some memory (azimuthal asymmetry) of the initial collision geometry. Knowledge of the reaction plane (RP) orientation is very important for the following physics tasks:

- Elliptic and directed flows of mesons, nucleons, hyperons and hypernuclei;
- Femtoscopy Correlations w.r.t. RP;
- Global polarization (w.r.t. RP) of hyperons (Λ, Ξ, Ω);
- Vector mesons alightment w.r.t. RP , measured by dilepton yield asymmetry;
- Charge asymmetry w.r.t. RP, CME.

In this report we perform the feasibility study of MPD, including the Time Projection Chamber, TPC, and Zero Degree Calorimeter, ZDC, to reconstruct the RP. Reconstruction of RP is performed with the usage of the directed flow of emitted particles in simulated non-central events. RP resolution is estimated for several acceptances or sizes of ZDC.

2 Event Simulation

The main event generator used to simulate nucleus-nucleus collisions is UrQMD. However, it does not describe processes of spallation and (multi)fragmentation of the residual nucleus, inasmuch as, according to the model all spectator nucleons after interaction time fly away unbounded. It leads to significant deformation of the forward/backward (pseudo)rapidity spectra of the products of collision. In comparison with UrQMD the more realistic spectra in forward/backward direction is given by the generator LAQGSM (Fig. 1) [1]. LAQGSM includes the statistical model of multifragmentation and evaporation model for emission of nucleons and light fragments from the excited residuals. Namely, lack of fragments in UrQMD results in difference of spectra in the forward/backward direction.

The samples of 10^5 minbias LAQGSM events for cms energies 3, 5, 7, 9, 11 GeV have been simulated. The preliminary analysis has shown that the maximal value of the directed flow takes place at the impact parameter range 5 - 9 fm. The corresponding range of centrality is near 10% - 30%. Since the maximal resolution of the RP is reached at the maximal flows (elliptic or directed) one should be able to select events by observables relating to centrality, measured in TPC or/and ZDC.

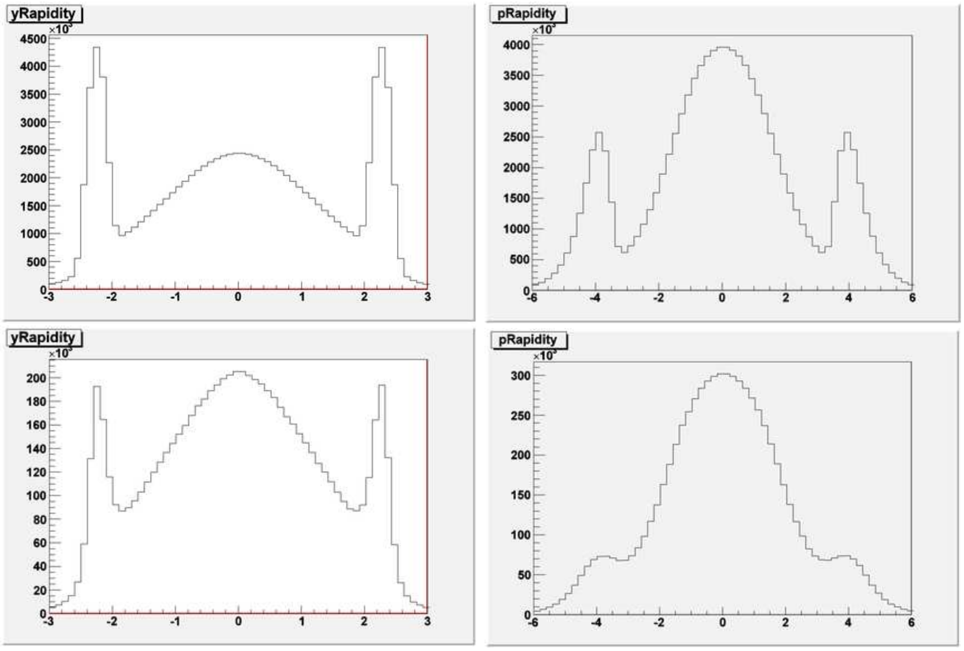

Figure 1: Upper row: Rapidity (left panel) and pseudorapidity (right panel) distributions of charged particles, given by UrQMD. Lower row: Rapidity (left panel) and pseudorapidity (right panel) distribution of charged particles, given by LAQGSM. All distributions are simulated at $\sqrt{s} = 9$ GeV.

3 Centrality Determination

There are two methods of centrality determination in MPD. In the first method one can use the information on the number of tracks in TPC with acceptance corresponding to the pseudorapidity region $-1.2 < \eta < 1.2$. In the second one centrality is determined by the energy losses of particles in ZDC which covers the pseudorapidity region $2.5 < |\eta| < 5.0$. Two-dimensional plot of track multiplicity in TPC vs. impact parameter, b, for all NICA energies is shown in the left panel of Fig. 2. Calculated relations between the event multiplicity, impact parameter and centrality are given in the right panel of Fig. 2. Applying these relations one can select events with needed centrality from the track multiplicity in TPC for minimum bias events shown in Fig. 3. Right panel of this Figure demonstrates the corresponding participant number distribution calculated by the Glauber MC model "Glissando" [2]. Centrality range 10% - 30% corresponds to our preferred range of the impact parameter. For the fixed (measured) track multiplicity in TPC the impact parameter is defined with the precision $\sigma = \pm 0.8 fm$. On the other hand centrality can be selected by the energy losses of emitted particles in Zero Degree Calorimeter, ZDC. Dependence of energy losses in ZDC on the impact parameter at all NICA energies is shown on the left panel of Fig. 4. As seen from the Figure this dependence has a non-monotonic behavior. One can reduce this ambiguity by the simultaneous measurement of track multiplicity in TPC. Right panel in this Figure demonstrates correlation between the energy loss in ZDC and track multiplicity in TPC. This correlation for $\sqrt{s} = 9$ GeV is shown in Fig. 5 with selected regions of centrality. Nevertheless, it is preferable to measure centrality by the track multiplicity in TPC than by the energy loss in ZDC, because the latter method results in a larger spread of impact parameter and corresponding centrality values, as well. The detailed analysis of ZDC feasibility for centrality determination has been performed in paper [3].

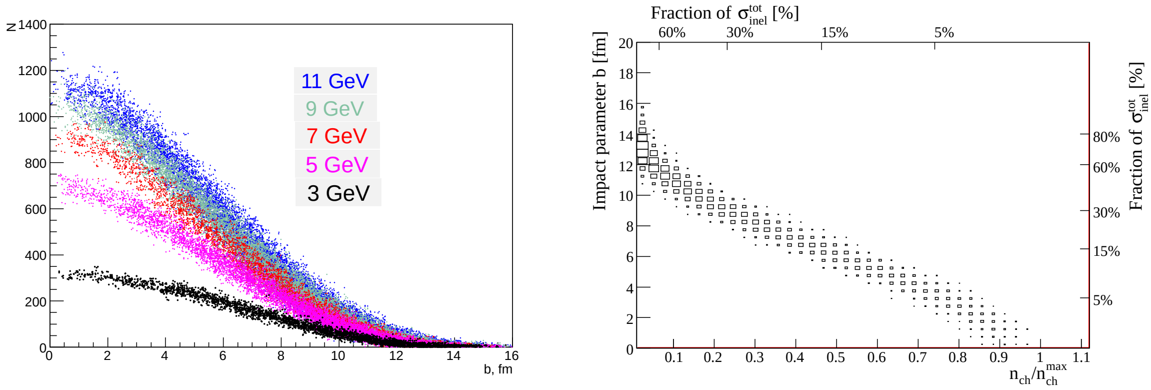

Figure 2: Left panel) Two-dimensional plot of track multiplicity in TPC versus impact parameter of the event. Right panel) Relationship between the normalized event multiplicity, impact parameter and centrality.

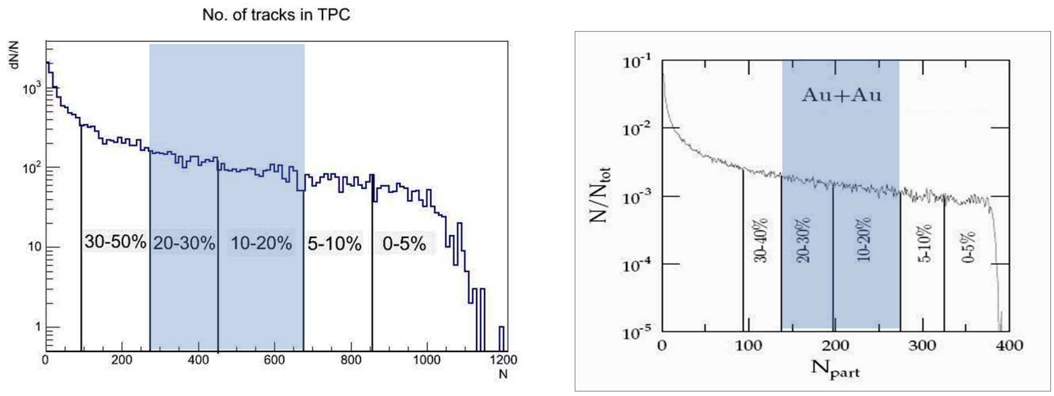

Figure 3: Left panel: Track multiplicity distribution in TPC at $\sqrt{s} = 9$ GeV with selected ranges of centrality. Right panel: Corresponding participant multiplicity distribution.

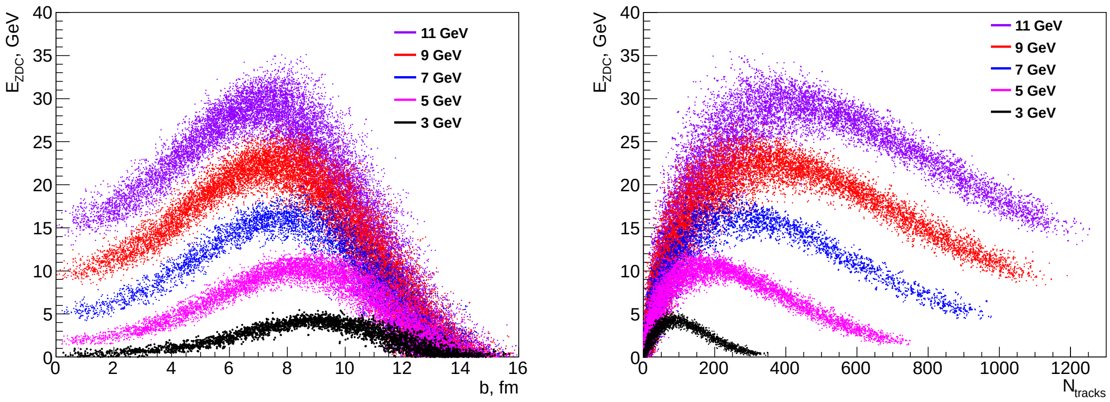

Figure 4: Left panel: The energy losses in ZDC vs impact parameter, b. Right panel: The energy losses in ZDC vs track multiplicity in TPC.

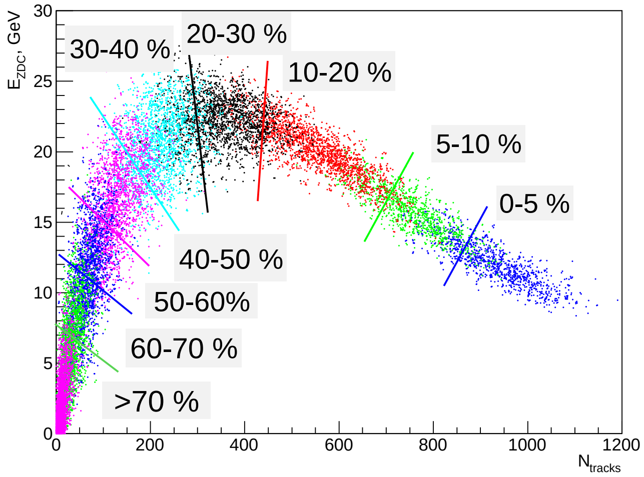

Figure 5: The energy losses in ZDC vs track multiplicity in TPC at $\sqrt{s} = 9$ GeV with the selected ranges of centrality.

4 Reaction Plane reconstruction

In any non-central event one can define the Event Plane (EP) orientation angle, Ψ which can be determined from the measured 1-st harmonic by the standard method:

$$\Psi_{EP} = \arctan \frac{\sum \omega_i \sin(\varphi_i)}{\sum \omega_i cos(\varphi_i)}, \tag{1}$$

where φ_i is the azimuthal angle of i-th particle and ω_i is the weight. The sum runs over all particles in a given event. A procedure to optimize the weights is usually needed in order to achieve the best accuracy, e.g. using the particle transverse momentum, $\omega_i = p_{Ti}$. The width of distribution of the Event Plane angle around the 'true' RP angle,

$$< \Delta\Psi_{RP} >=< |\Psi_{EP} - \Psi_{RP}| >, \tag{2}$$

and

$$R =< cos(\Delta\Psi_{RP}) > \tag{3}$$

characterize the resolution of the RP reconstruction.

In MPD the EP can be reconstructed by measuring cell-by-cell energy losses in ZDC. The azimuthal angle Ψ characterizing the orientation of EP is defined by the expression

$$\Psi_{EP} = \arctan \frac{\sum \Delta E_i y_i}{\sum \Delta E_i x_i}, \tag{4}$$

where ΔE_i is the energy loss in the cell i with coordinates x_i and y_i. In this procedure one encounters with the problem of non-identification of particles. Since the EP orientation (in our case) relates to a directed flow defined as

$$v_1 = \langle \frac{p_x}{\sqrt{p_x^2 + p_y^2}} \rangle, \tag{5}$$

the flow vector has opposite sign for mesons in comparison with nucleons and nuclear fragments, and the EP orientation behaves the same manner. So contributions to the EP angle coming from mesons on one hand, and nucleons and nuclear fragments on the other hand have opposite signs (Fig. 6). Inasmuch as ZDC does not provide the information on particle identification one should estimate distortion introduced by pions into the RP reconstruction. The relative contributions of charged pions and nucleons with nuclear fragments to the energy loss in the ZDC can be estimated from comparison of their pseudorapidity spectra shown in Fig. 7. As seen from the Figure, emission of charged pions into ZDC acceptance in comparison with of nucleons and nuclear fragments is negligible up to 5 GeV. However, their contribution to the energy loss in ZDC monotonically

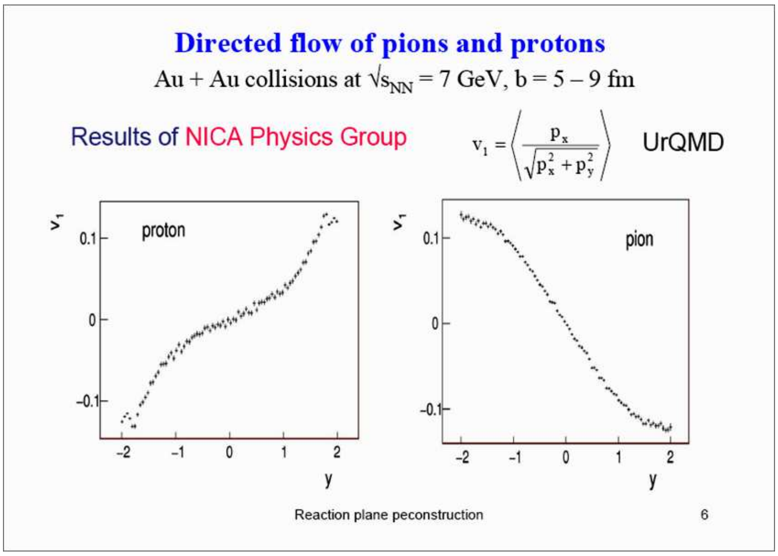

Figure 6: Directed flow of protons and charged pions versus rapidity at $\sqrt{s} = 7$ GeV.

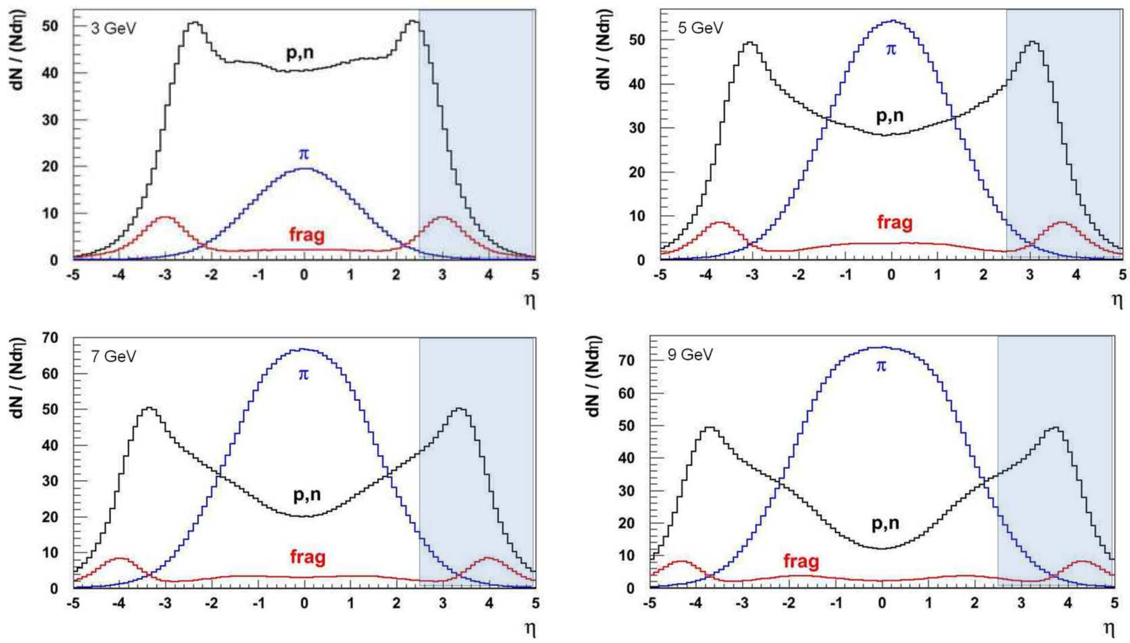

Figure 7: Pseudorapidity distributions of charged pions, nucleons and nuclear fragments (frag) simulated by LAQGSM at $\sqrt{s} = 3$, 5 GeV (upper row) and 7, 9 GeV (lower row). Blue bands refer to the ZDC acceptance.

Table 1: Acceptances and sizes (radii) of ZDC.

η	θ, degree	R, cm
2.5 - 5.0	9.4	60.4
2.7 - 5.0	7.68	49.0
2.9 - 5.0	6.3	40.3
3.1 - 5.0	5.16	33.0

Table 2: Reaction Plane resolution as width of angular distribution of RP orientation, $< \Delta\Psi_{RP} >$.

η	2.5 - 5.0			2.7 - 5.0			2.9 - 5.0			3.1 - 5.0		
	p+n	p+n+pi	all	p+n	p+n+pi	all	p+n	p+n+pi	all	p+n	p+n+pi	all
3 GeV	47.6	47.8	39.7	58.1	58.3	49.2	67.9	67.9	57.7	74.4	74.4	64.2
5 GeV	30.3	31.2	27.1	35.6	36.1	31.7	41.6	42.2	37.5	49.2	49.6	44.7
7 GeV	24.7	26.5	23.2	28.4	29.6	26.1	33.0	33.7	29,8	38.4	38.9	35.2
9 GeV	22.2	24.5	21.8	23.4	25.6	22.8	26.4	27.7	24.7	30.2	31.2	28.1
11 GeV	22.8	26.3	23.6	23.1	25.5	22.9	24.5	26.3	23.7	27.2	28.6	25.6

increases at higher energies because of the increasing pion production in the whole rapidity interval. Peaks in nuclear fragments distributions correspond to spectator fragments produced by the residual nuclei spallation. The remaining part of spectra is caused by coalescence mechanism of the light fragments production. Using Eq. (1) we can estimate distortions brought in by pions to RP reconstruction at the level of MC events. Analysis has been performed for different ZDC sizes or acceptances which have been selected by pseudorapidity intervals (see Table 1). The maximal value of pseudorapidity, 5.0, in all intervals corresponds to the ZDC's hole, and the maximal acceptance, 2.5 - 5.0, corresponds to the transverse size of ZDC. Tables 2 and 3 demonstrate dependence of the resolution of the RP reconstruction in MC events on the energy and pseudorapidity intervals separately for i)nucleons, ii)nucleons plus charged pions identified as nucleons and iii)nucleons plus charged pions plus nuclear fragments (all). Nuclear fragments evidently improve the RP resolution for all acceptances. Deterioration of the RP resolution caused by pion contamination increases with the collision energy and reach $\sim 3\%$ at 11 GeV. RP resolutions for different ZDC acceptances, and for all particles identified as nucleons, are shown in the Fig. 8. RP resolution, which is maximal for the whole ZDC acceptance at each energy, increases with the energy of collision.

Comparison of the RP resolution calculated by Eq. (1) for MC events and reconstructed by the energy losses (Eq. (4)) in ZDC (RECO) for all above acceptances is shown in Figure 9. RP resolution for both MC and reconstructed events is maximal for the maximal ZDC acceptance. At the same time the RP resolution reconstructed by ZDC deteriorates. The maximal deviation of the reconstructed RP resolution from the MC value is ($\sim 8\%$) at lowest collision energies and maximal ZDC acceptance.

Performed analysis demonstrates that decrease of the transverse size of ZDC from 60.4 cm to 33.0 cm, corresponding to reduction of ZDC acceptance from 2.5 to 3.1 in pseudorapidity space, results in two times RP resolution decrease.

Table 3: Reaction Plane resolution in terms of $R =< cos(\Delta\Psi_{RP}) >$.

η	2.5 - 5.0			2.7 - 5.0			2.9 - 5.0			3.1 - 5.0		
	p+n	p+n+pi	all	p+n	p+n+pi	all	p+n	p+n+pi	all	p+n	p+n+pi	all
3 GeV	0.67	0.67	0.77	0.50	0.50	0.64	0.32	0.32	0.51	0.19	0.19	0.38
5 GeV	0.87	0.86	0.89	0.82	0.81	0.86	0.75	0.74	0.8	0.65	0.65	0.71
7 GeV	0.91	0.9	0.92	0.88	0.87	0.90	0.84	0.84	0.87	0.79	0.78	0.82
9 GeV	0.93	0.91	0.93	0.92	0.91	0.93	0.9	0.9	0.91	0.87	0.86	0.88
11 GeV	0.92	0.9	0.92	0.92	0.91	0.92	0.91	0.9	0.92	0.89	0.88	0.91

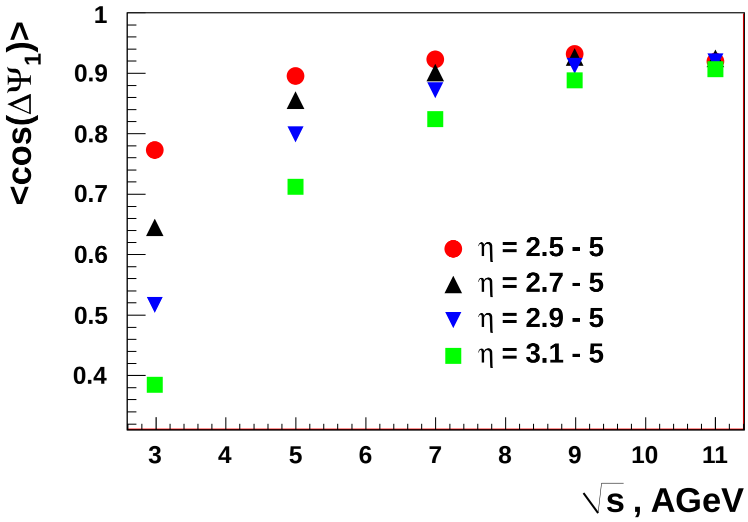

Figure 8: Dependence of the Reaction Plane resolution for MC events on the collision energy for different pseudorapidity intervals without particle identification.

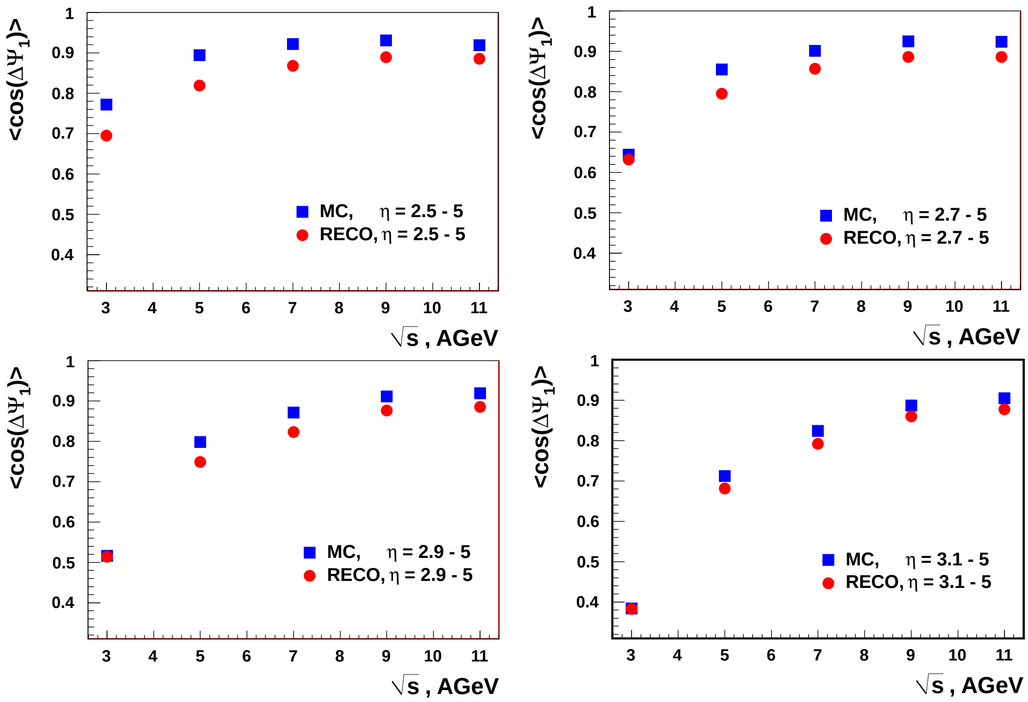

Figure 9: The Reaction Plane resolution calculated for MC and reconstructed events for different ZDC acceptances versus the collision energy.

References

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