Comparison of different centrality determination methods at the BM@N experiment

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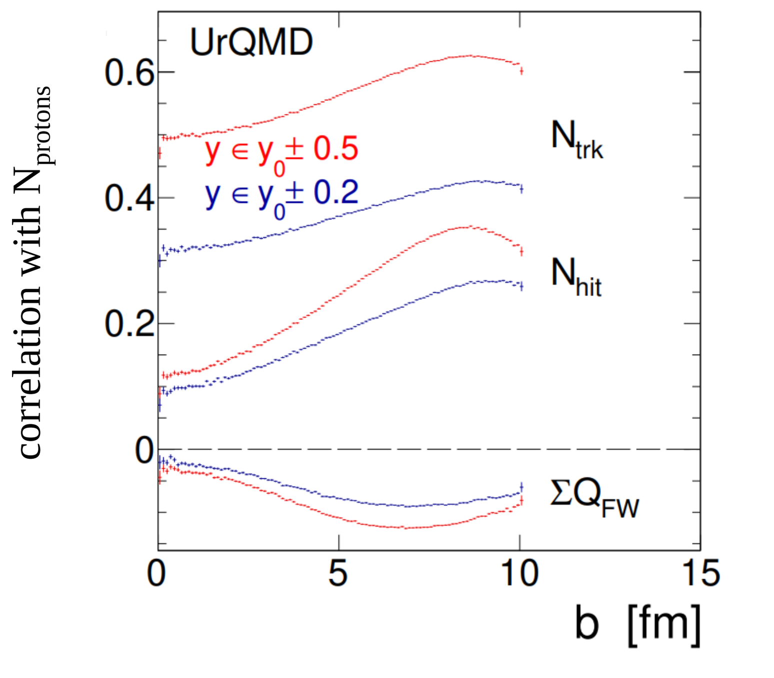
The centrality determination procedure provides an estimate of the initial geometry in heavy ion collisions through a connection between the observable and the impact parameter. The multiplicity of produced charged particles and the Monte Carlo Glauber model is usually used to determine the centrality. However, there are difficulties in using this approach at NICA collider energies due to the large uncertainty of the impact parameter at small multiplicity, autocorrelation effect, etc. New approach to determine the centrality based on Bayes' theorem and two-dimensional Gamma distribution is proposed. This method allows to obtain information about the impact parameter by using only the measured two-dimensional energy distribution of spectator nucleons and the multiplicity of produced charged particles. A new method to account for the efficiency of the detector system and the pileup is also proposed. The performance of the proposed approach has been tested on the data from the BM@N experiment and simulation data from the DCM-QGSM-SMM model for Xe+CsI collisions at a beam energy of 3.8A GeV.

Centrality

- Evolution of matter produced in heavy-ion collisions depend on its initial geometry
- Centrality procedure maps initial geometry parameters with measurable quantities (multiplicity or transverse energy of the produced particles)
- **This allows comparison of the BM@N and future MPD results with the data from other experiments (STAR BES, NA49/NA61 scans) and theoretical models**



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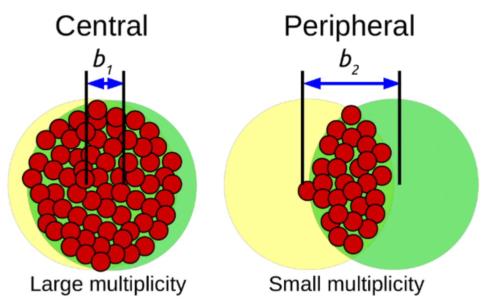
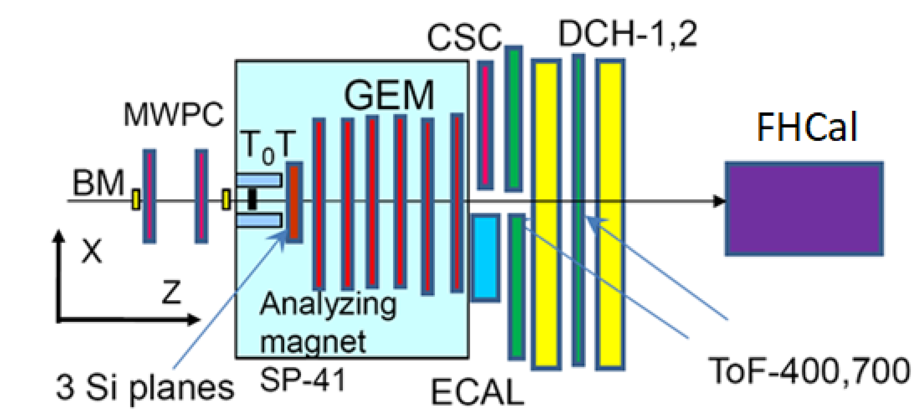
$$c(b) = \frac{\int_0^b \frac{d\sigma}{db'}db'}{\int_0^\infty \frac{d\sigma}{db'}db'} = \frac{1}{\sigma_{A-A}}\int_0^b \frac{d\sigma}{db'}db'$$



- A number of produced protons is stronger correlated with the number of produced particles (track & RPC+TOF hits) than with the total charge of spectator fragments (FW)
- to suppress self-correlation biases, it is necessary to use spectators fragments for centrality estimation

Centrality determination in BM@N

DCM-QGSM-SMM → GEANT4 → Reconstruction → Centrality det.

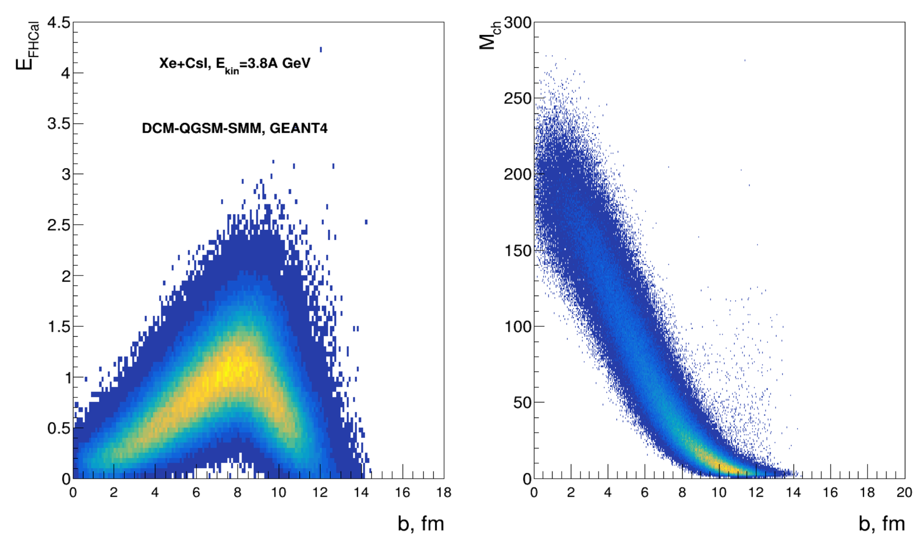


Centrality determination: Multiplicity of produced charged particles in tracking system

Energy of spectators from the FHCal

Simulated data sets: Xe+CsI, Nev=500k

Experimental data: Run 8, with CCT2 triger



- due to the beam hole, there is no unique correlation between the energy from the calorimeter and the impact parameter, thus it is necessary to use the second observable

The Bayesian inversion method (Γ-fit): 2D fit

- The fluctuation kernel for energy and multiplicity at fixed impact parameter can be describe by 2D Gamma distr.:

$$\boxed{P(E,M\,|\,c_b) = G_{2D}(E,M\,|\,c_b)}$$

$$c_b = \int_0^b P(b')db'$$ – centrality based on impact parameter

$\langle E\rangle, D(E)$ – average value and variance of energy

$\langle M\rangle, D(M)$ – average value and variance of mult.

$R(E,M)$ – Pirson correlation coefficient

$$\boxed{R(E,M) = \varepsilon_1 \cdot m_1 \cdot R(E',M')\sqrt{\frac{D(E')D(M')}{D(E)D(M)}}}$$

$\langle E'(c_b)\rangle$ – average value and var. of energy/mult. $D(E'(c_b))$ from the rec. model data

$$\boxed{\begin{aligned}&\langle E\rangle = \varepsilon_1\langle E'(c_b)\rangle + \varepsilon_0, \quad D(E) = \varepsilon_2 D(E'(c_b))\\ &\langle M\rangle = m_1\langle M'(c_b)\rangle,\\ &D(M) = m_1^2\cdot D(M') + m_1\cdot m_2\langle M'\rangle\end{aligned}}$$

$\langle E'(c_b)\rangle$, $D(E'(c_b))$ - can be approximated by polynomials

$$\langle E'(c_b)\rangle = \sum_{j=1}^{12} a_j c_b^j, \quad D(E'(c_b)) = \sum_{j=1}^{19} b_j c_b^j$$

$$\langle M'(c_b)\rangle = \sum_{j=1}^{12} a_j c_b^j, \quad D(M'(c_b)) = \sum_{j=1}^{6} b_j c_b^j$$

$\varepsilon_0, \varepsilon_1, \varepsilon_2, m_1, m_2$ - fit parameters

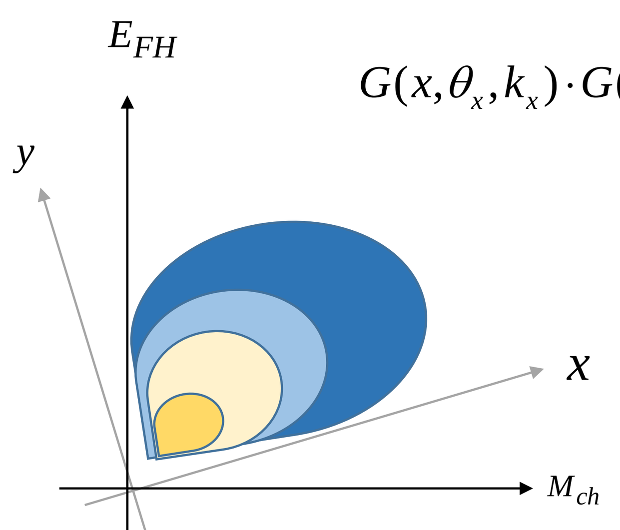
2D Gamma distribution

It is possible to find such a rotation angle of the system that $\mathrm{cov}(x,y) = 0$

Then the two-dimensional distribution in the new coordinate system will be

$$G_{2D}(E_{FH}, M_{ch}, \langle E\rangle, \langle M\rangle, D(E), D(M), R) = G(x,\theta_x,k_x)\cdot G(y,\theta_y,k_y)$$

$$G(x,\theta_x,k_x)\cdot G(y,\theta_y,k_y) = \frac{(x)^{k_x(c_b)-1}e^{-x/\theta_x}}{\Gamma(k_x(c_b))\theta_x^2}\cdot\frac{(y)^{k_y(c_b)-1}e^{-y/\theta_y}}{\Gamma(k_y(c_b))\theta_y^2}$$



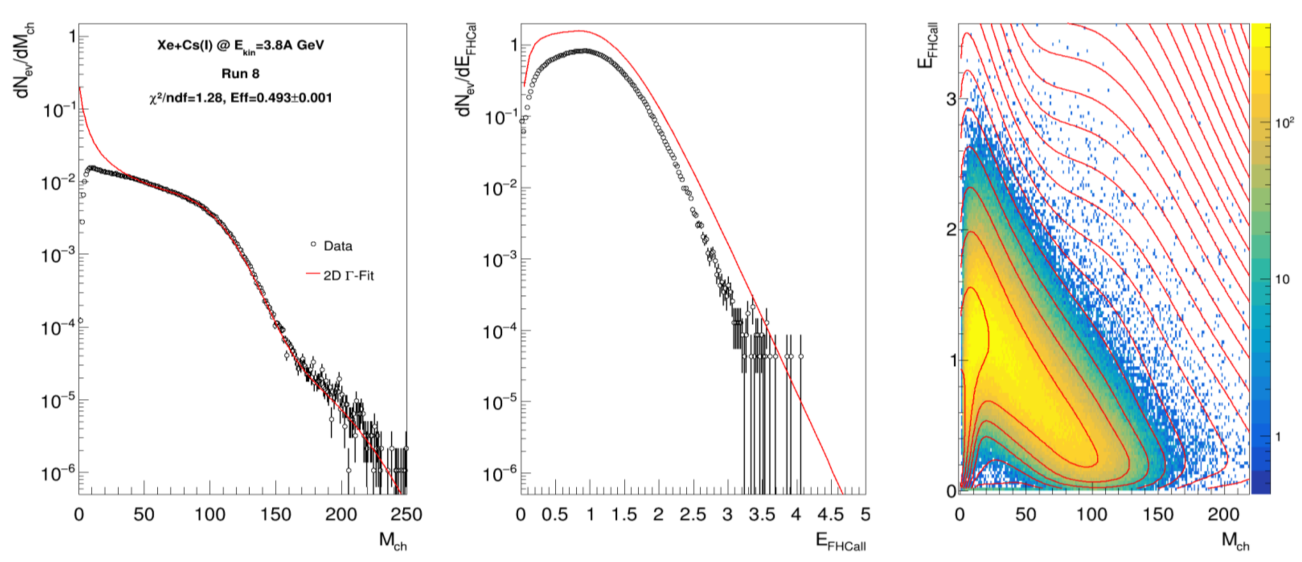
$$\boxed{\begin{aligned}&\theta_x = \frac{D(x)}{\langle x\rangle}, \quad k_x = \frac{\langle x\rangle^2}{D(x)}, \theta_y = \frac{D(y)}{\langle y\rangle}, \quad k_y = \frac{\langle y\rangle^2}{D(y)}\\ &\alpha = \arctan\left(\frac{2\sqrt{D(E)D(M)}R(E,M)}{D(E)-D(M)}\right)\end{aligned}}$$

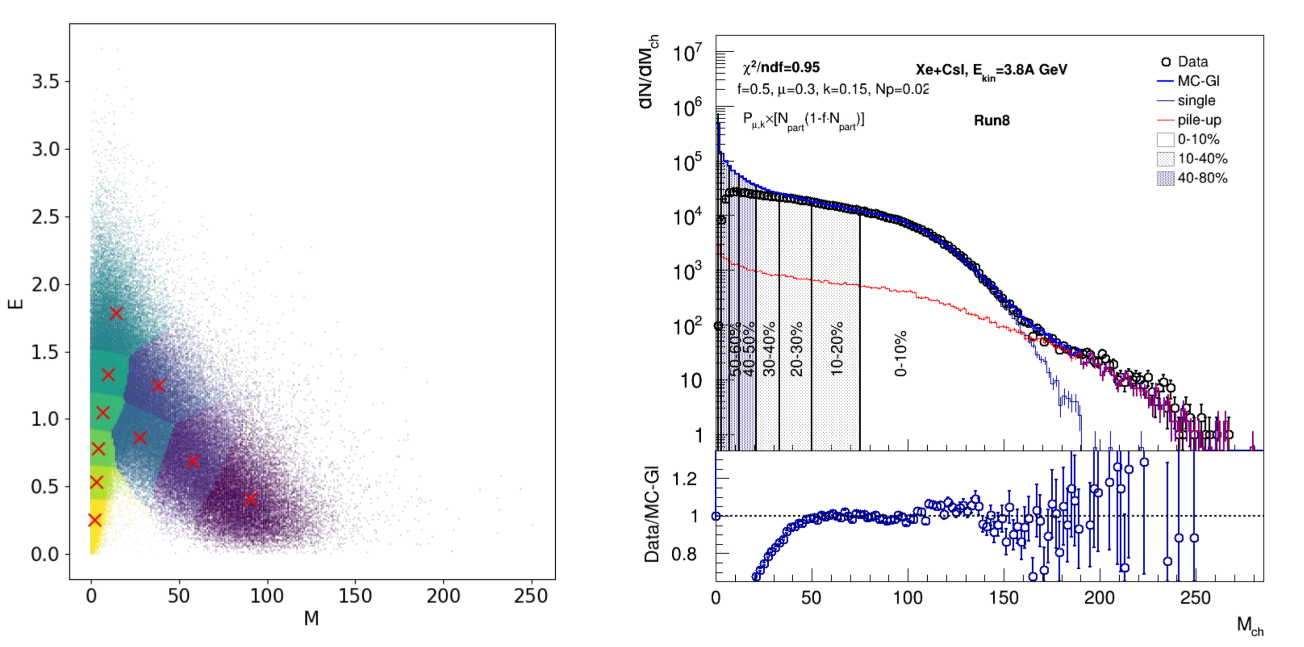
mean value and variance in the new coordinate system

$$\langle x\rangle = \cos(\alpha)\langle E\rangle + \sin(\alpha)\langle M\rangle \qquad D(x) = D(E)\cos(\alpha)^2 + R(E,M)\sqrt{D(E)D(M)}\sin(2\alpha) + D(M)\sin(\alpha)^2$$

$$\langle y\rangle = -\sin(\alpha)\langle E\rangle + \cos(\alpha)\langle M\rangle \qquad D(y) = D(E)\sin(\alpha)^2 - R(E,M)\sqrt{D(E)D(M)}\sin(2\alpha) + D(M)\cos(\alpha)^2$$

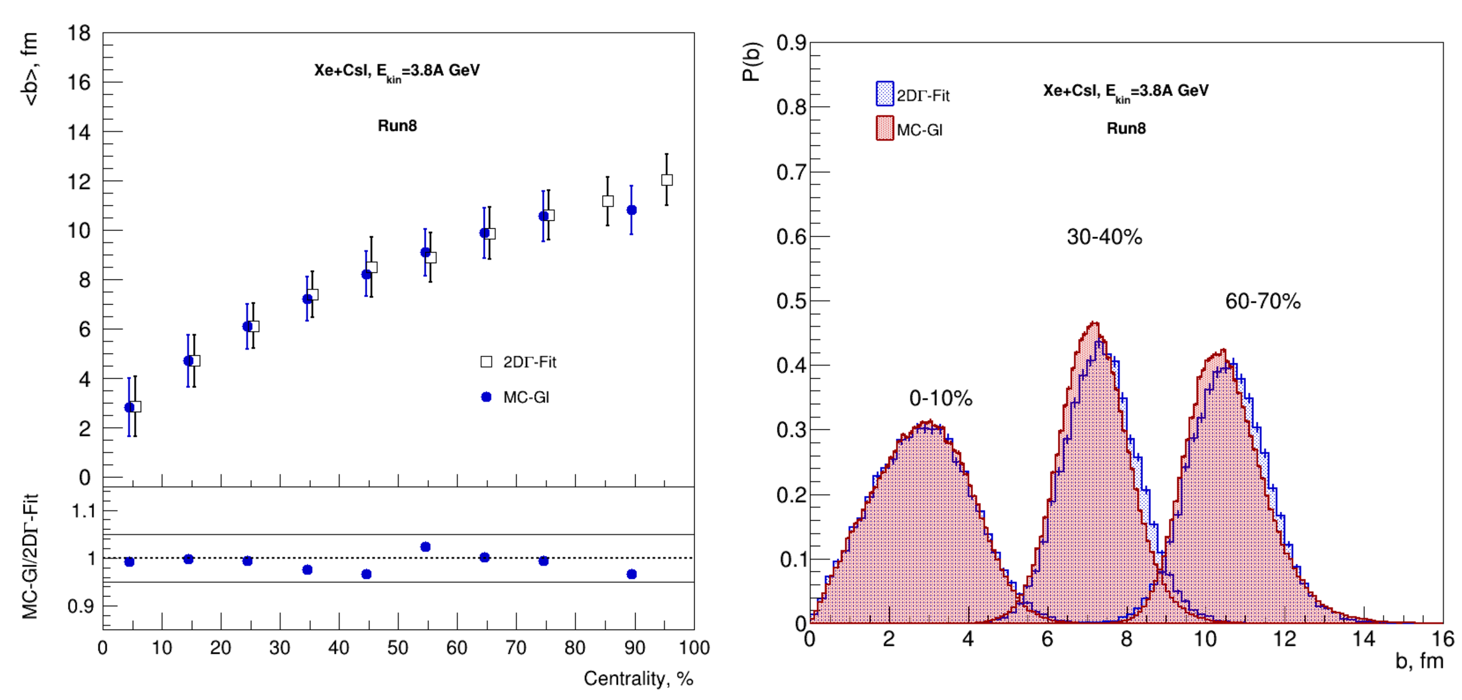
Fit results





Good agreement between fit and data. Difference in energy distribution due to efficiency

Comparison with MC-Glauber fit



There is agreement within 5%.

Summary and outlook

- A new approach for centrality determination with energy of spectators and multiplicity of charged particles was proposed and compared with MC-Glauber method.
- The proposed method was applied to the data from BM@N experiment
- It is planned to create a two-dimensional method based on a signal from a hodoscope and energy from the FHCal.