First results on centrality determination in Xe+W and Xe+Xe collisions at E_{kin} =2.5 AGeV with MPD-FXT

Production 35 & 36

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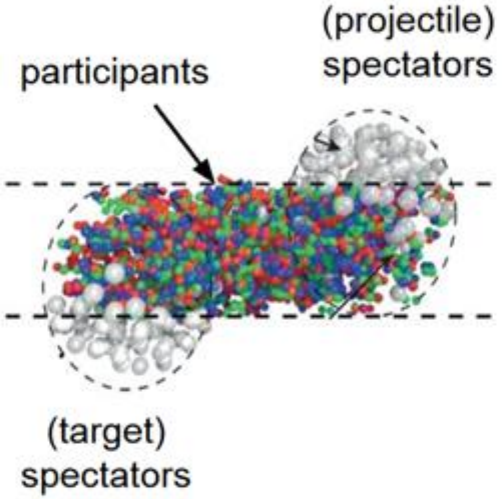
Motivation for centrality determination

- Size and evolution of matter created in a heavy-ion collisions highly depends on collision geometry;
- Goal of centrality determination is to connect (map) collision geometry parameters to experimentally observed variables;
- Therefore, one can group collisions into several **centrality classes**:

$$c_S = \frac{1}{\sigma_{inel}^{AA}} \int_{S_1}^{S_2} \frac{d\sigma}{dS} dS \qquad [1]$$

σ_{inel} – inelastic cross-section of a nucleus-nucleus collision;
S, S_1, S_2 – centrality classes; S_1, S_2 – centrality classes for events at given fraction (in %) of the total cross section.



- The less the impact parameter *b* and higher multiplicity -> the more central the collision (and vice versa).

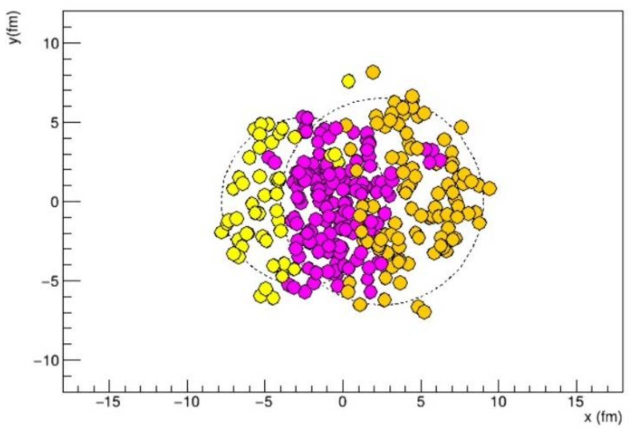
[1] - P.Parfenov et al. https://github.com/FlowNICA/CentralityFramework/blob/master/Documentation/Centrality_AnalysisNote.pdf

MC Glauber model

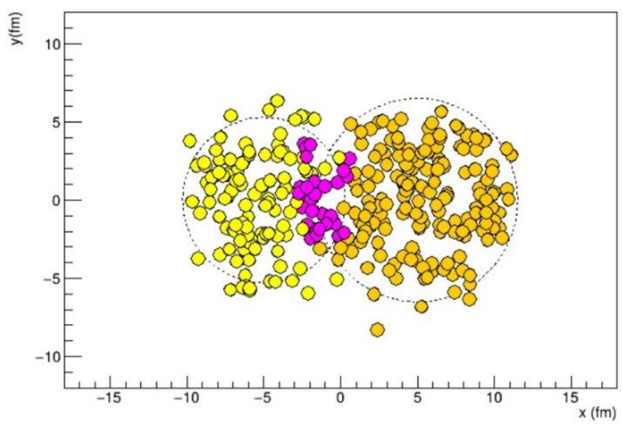
- Used for description of heavy ion collisions at high energies (at low energies not so good);
- Nuclei collisions treated as multiple nucleons collision;
- Nucleon distribution is random;
- Nucleons described by nucleon density (in our case by 2pF Fermi):

$$\rho(r) = \frac{1+\omega\left(\frac{r^2}{R^2}\right)}{1+\exp(\frac{r-R}{a})} \quad [2]$$

ω – central density depletion;
r – half-density radius;
a – surface diffuseness parameter;



Xe+W (σ = 24.1; b = 5 fm)



Xe+W (σ = 24.1; b = 10 fm)

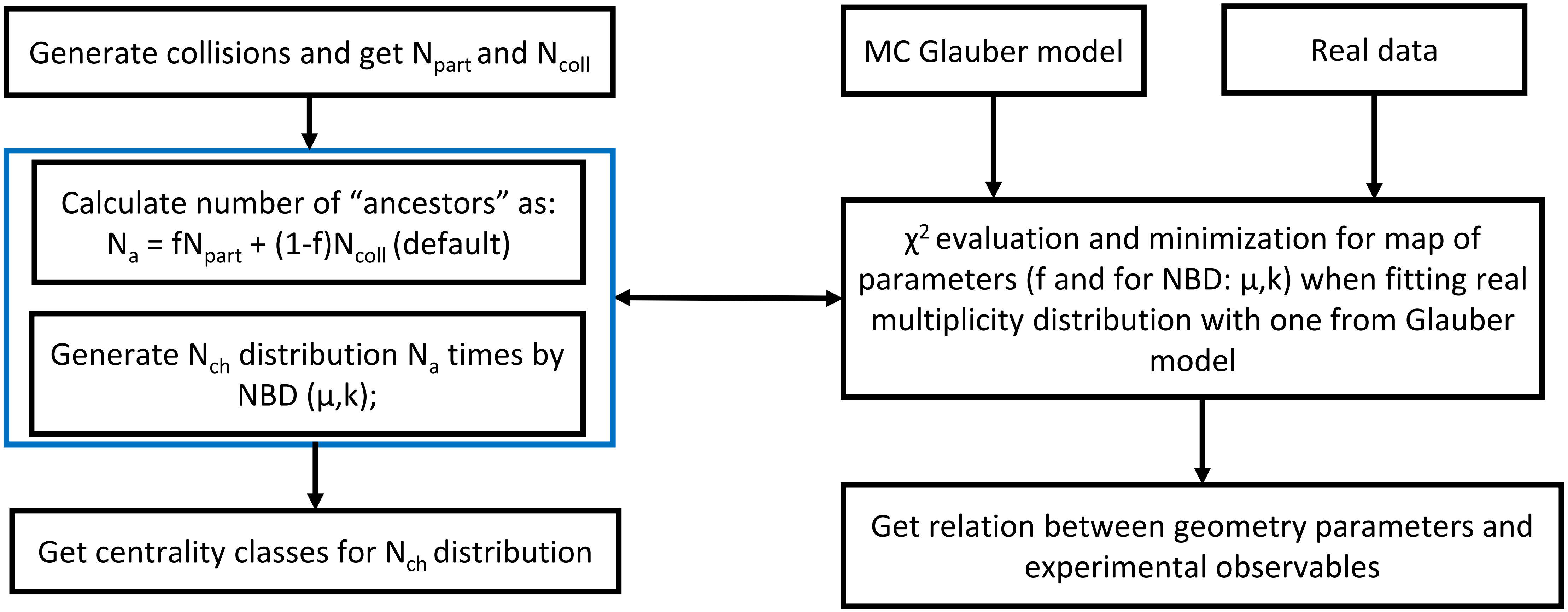
– Participants

– Spectators (Xe)

– Spectators (W)

[2] - B. Abelev et al., PhysRevC.88.044909. DOI: 10.1103/PhysRevC.88.044909

Centrality determination via MC Glauber model



Bayesian inversion method (Gamma-fit)

- Charged particle multiplicity and impact parameter are related by probability distribution as:

$$P(N_{ch}|b) = \frac{1}{\Gamma(k)\theta^k} N_{ch}^{k-1} e^{-N_{ch}/\theta} \qquad [1,3]$$

- c_b – cumulative probability distribution written as: $c_b = \int_0^\infty P(b')db'$.
- Mean multiplicity for centrality class based on impact parameter:

$$\langle N_{ch} \rangle = N_{knee} \exp\left(\sum_{i=1}^{3} a_i (c_b)^i\right)$$

- 5 parameters: $N_{knee}, \theta, a_1, a_2, a_3$;
- Fit function for multiplicity distribution:

$$P(N_{ch}) = \int_0^1 P(N_{ch}|c_b) dc_b$$

- Impact parameter for given multiplicity range at certain centrality class:

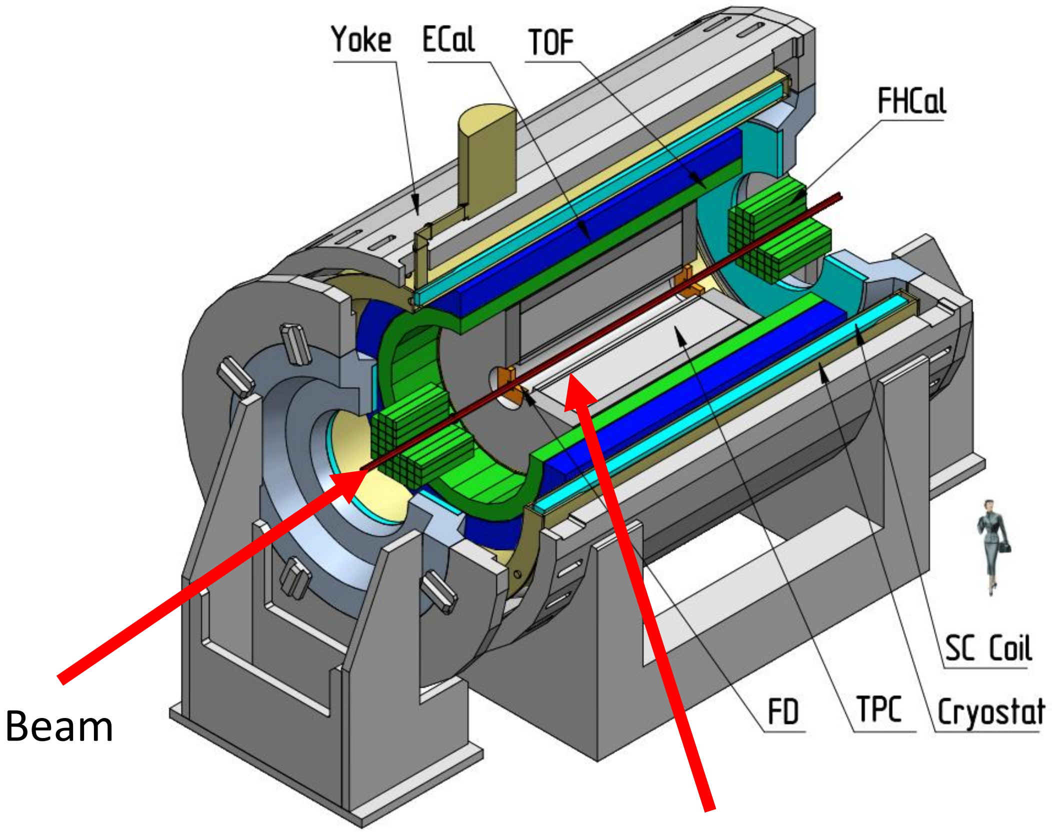
$$P\left(b|N_{ch}^{low} < N_{ch} < N_{ch}^{high}\right) = p(b) \frac{\int_{N_{ch}^{low}}^{N_{ch}^{high}} P(N'_{ch}|b) dN'_{ch};}{\int_{N_{ch}^{low}}^{N_{ch}^{high}} P(N'_{ch}) dN'_{ch};}$$

2 main steps of gamma-fit:

1) Fit multiplicity distribution from data with $P(N_{ch})$;
2) Construct impact parameter distribution using Bayes theorem.

[3] - R. Rogly, G. Giacalone, and J.-Y. Ollitrault, Phys. Rev. C, vol. 98, no. 2, p. 024 902, 2018.

Prod 35: Data analysis and centrality determination



Wire target (W/Xe):
Z = -85 cm;
d_{wire} = 100 µm;
Wire shifted by 1 cm upwards in Y

- Prod 35: Xe+W, 510k events;
  E_{kin} = 2.5 AGev; $\sqrt{s_{NN}}$ = 2.87 GeV;
- Prod 36: Xe+Xe, 1M events;
  E_{kin} = 2.5 AGev; $\sqrt{s_{NN}}$ = 2.87 GeV;
- Type of particle is defined via true-PDG value of associated track;
- Used selection criteria:
  - Only with charged particles;
  - Pseudorapidity η is from 0 to 2;
  - Rapidity *y* for MC simulation is from -0.5 to 2;

Parametrization of ^{124}Xe and ^{184}W

- Parametrization of target and incident nuclei was performed for ^{124}Xe and ^{184}W isotopes in TGlauNucleus.cc
- Parameters were taken from [4]. Deformation parameters $\beta_{2,3,4}$ are used for deformed nuclei.
- Parameters presented bellow:
- ^{124}Xe:
  - Mass number: fN = 124;
  - Nuclear radius: fR = 5.29;
  - Surface diffuseness par-r: fA = 0.58;
  - Central density depletion: fW = 0;
  - Type of dens. funct-n: fF = 8;
  - Atomic number: fN = 54;
  - β2 = 0.229; β4 = -0.018;
- ^{184}W:
  - Mass number: fN = 184;
  - Nuclear radius: fR = 6.51;
  - Surface diffuseness par-r: fA = 0.535;
  - Central density depletion: fW = 0;
  - Type of dens. funct-n: fF = 1;
  - Atomic number: fN = 74;

Note: Parameters for ^{184}W are calculated via scaling as:

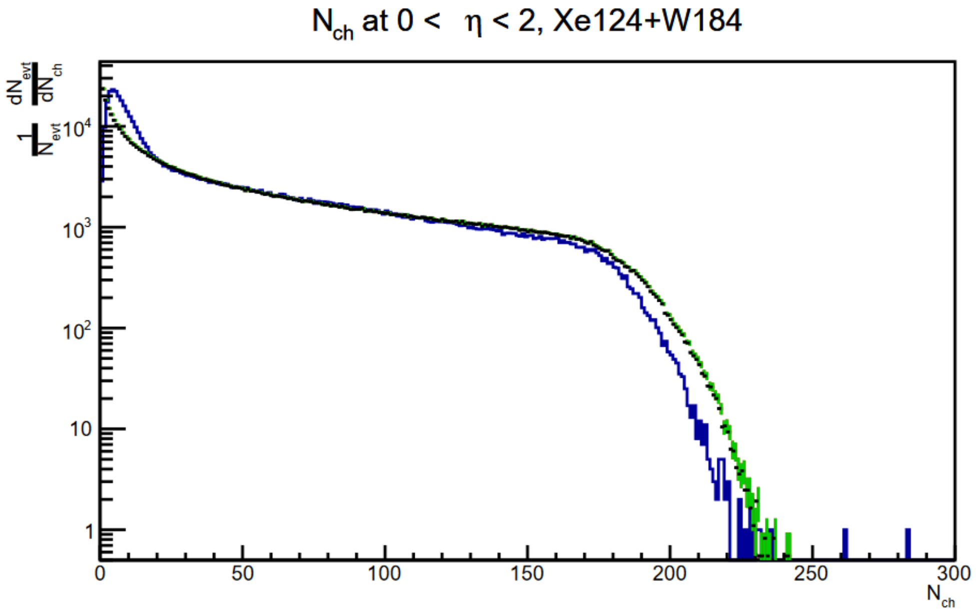
$$R(A) = R\left(\frac{A}{A_0}\right)^{1/3}, a(A) = a\left(\frac{A}{A_0}\right)^{1/3}; \quad [4]$$

A_0 – Mass number of main isotope

^{124}Xe and ^{184}W nuclei data was defined for MC Glauber model.

[4] – ALICE collaboration http://cds.cern.ch/record/2315401?ln=en

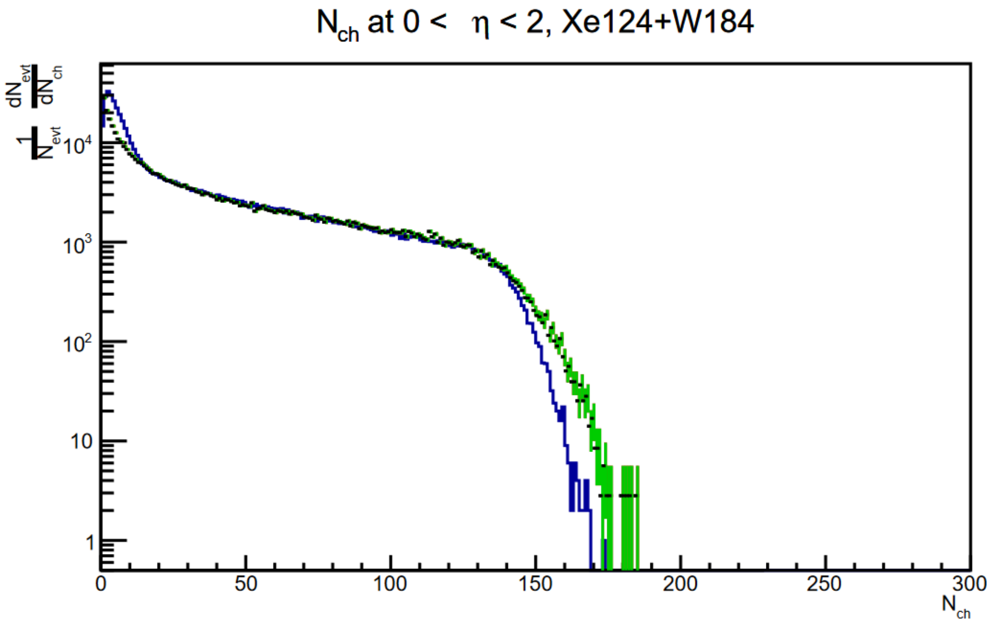
Prod 35: MC Glauber fit results



Histogram with **cuts 1**. Fit parameters:

$\mu = 0.62, f = 0.8, k = 53, \chi^2 = 2.815 \pm 0.115$

Cuts 1: 0 < η < 2; Charge ≠ 0;



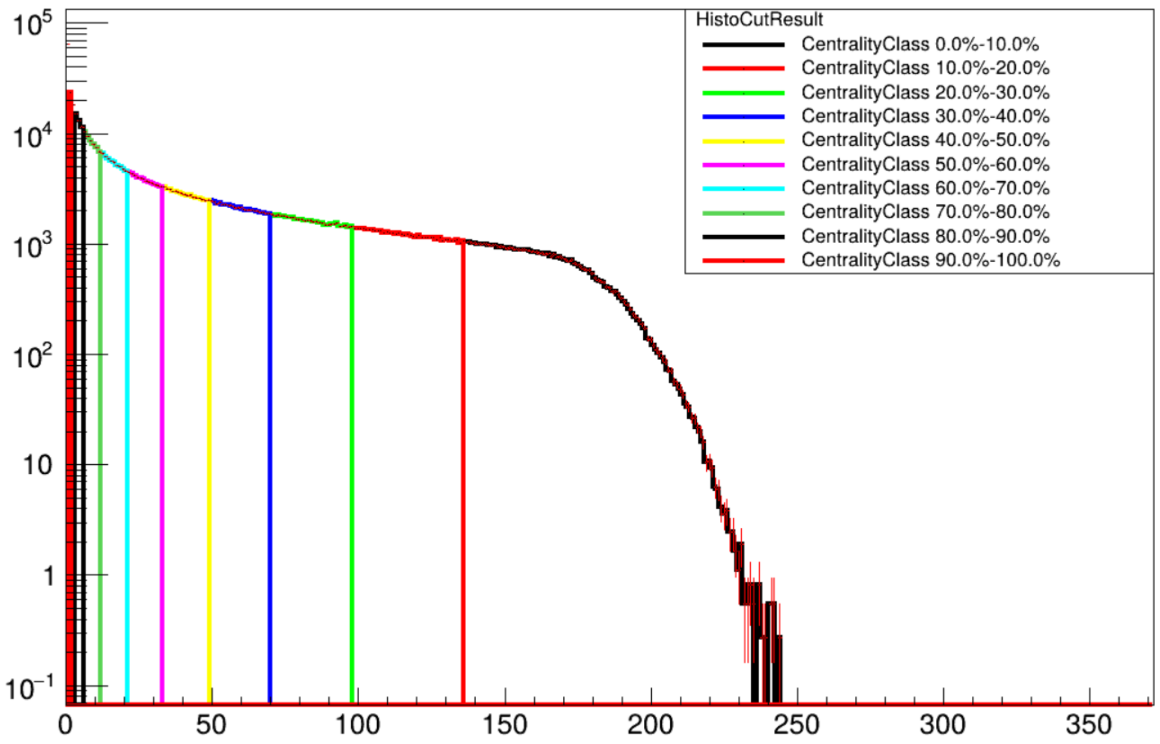
Histogram with **cuts 2**. Fit parameters:

$\mu = 0.436, f = 0.7, k = 50, \chi^2 = 6.212 \pm 0.143$

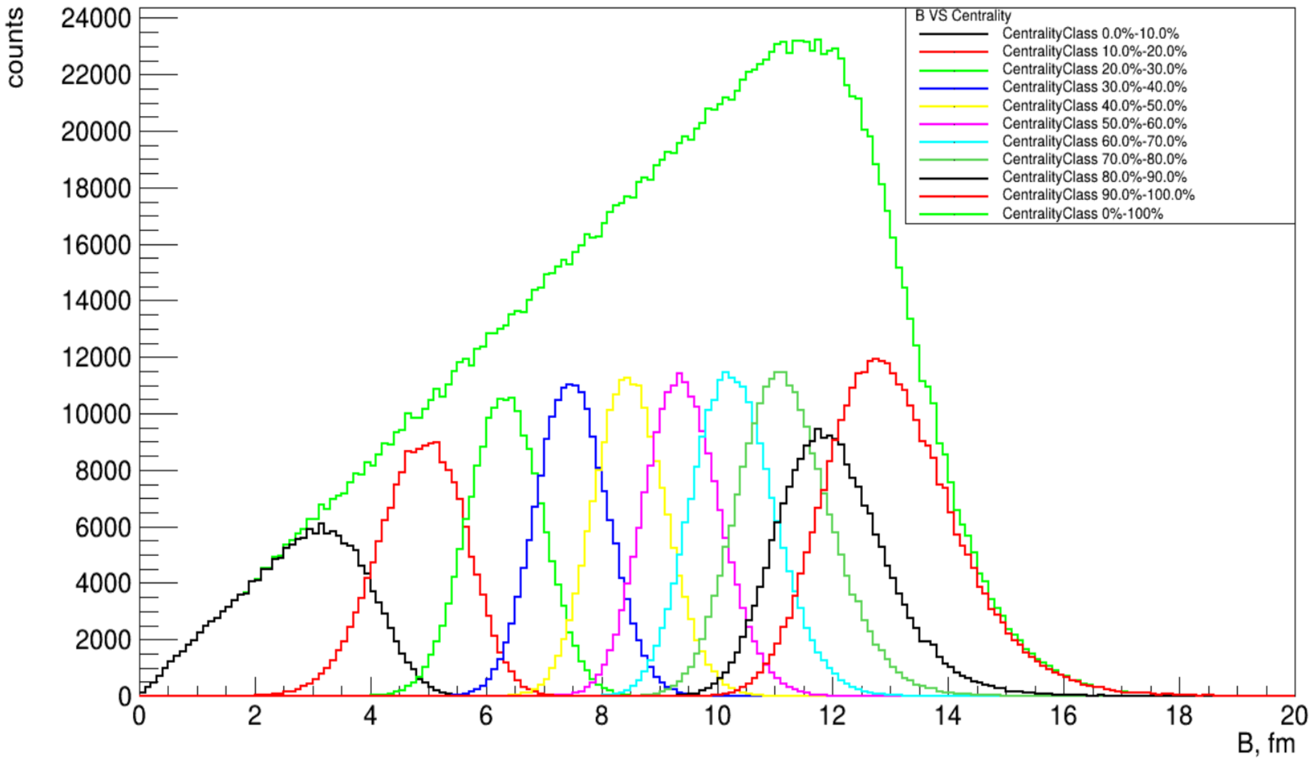
Cuts 2: 0 < η < 2; Charge ≠ 0; pT>0,2 GeV/c; Nhits>16

- **There is still no full agreement with data for most central collisions**

Prod 35: Centrality classes determination

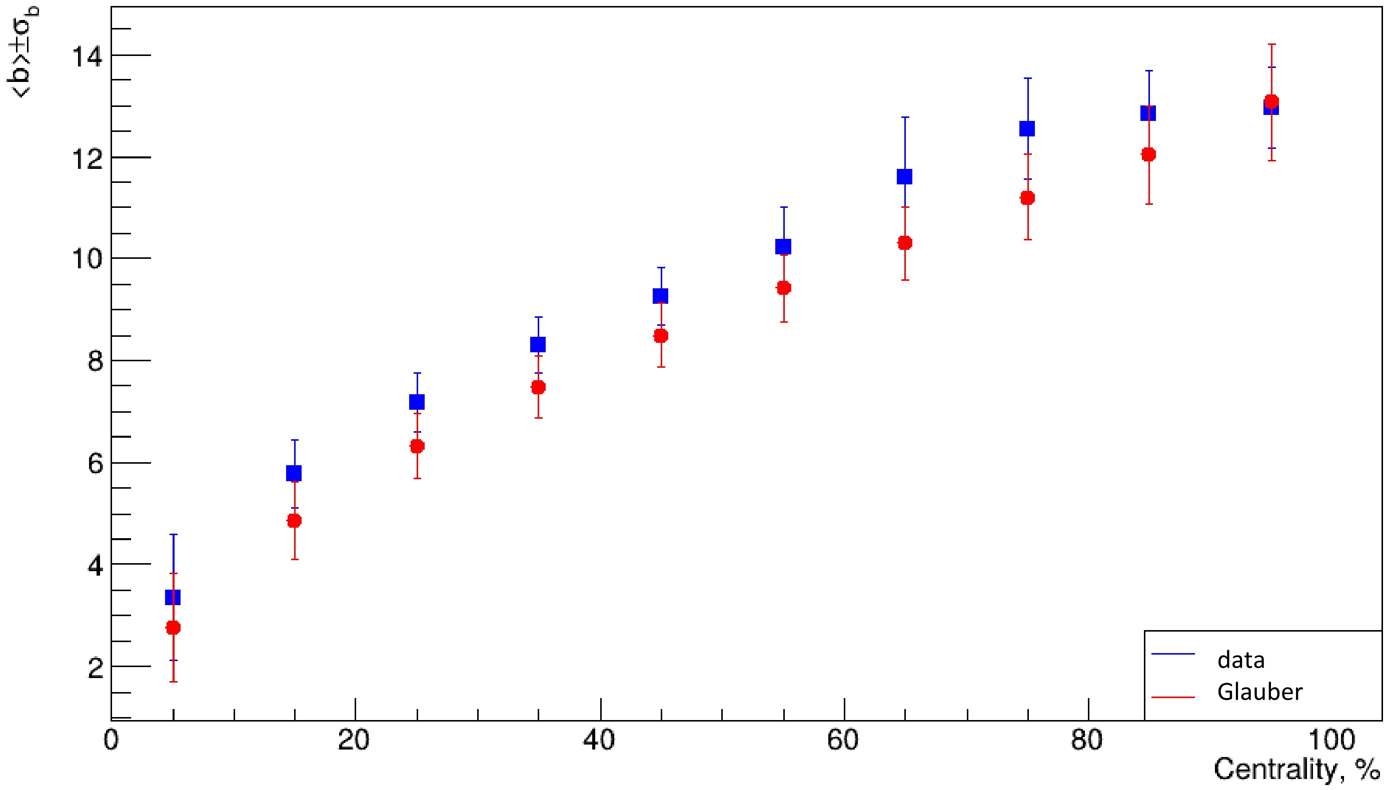


Distribution from MC Glauber NBD simulation with determined centrality classes



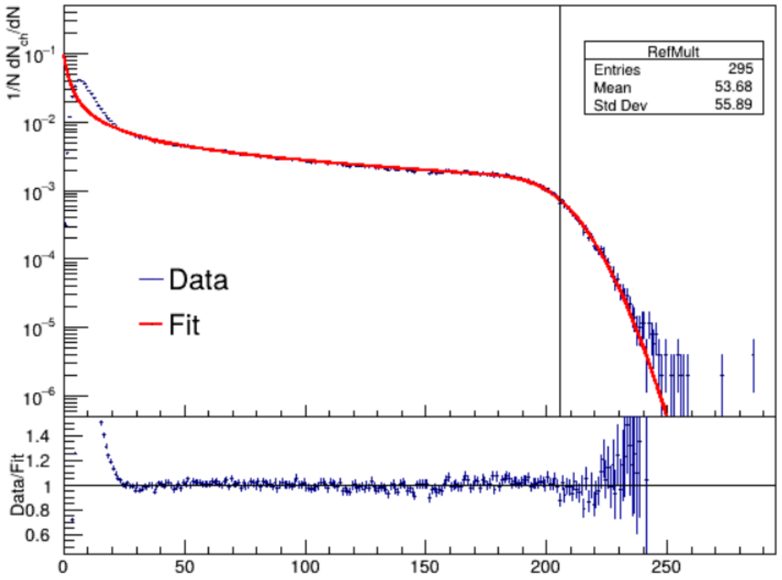
Impact parameter distributions in centrality classes for MC Glauber data

Prod 35: <b> vs Centrality for Glauber



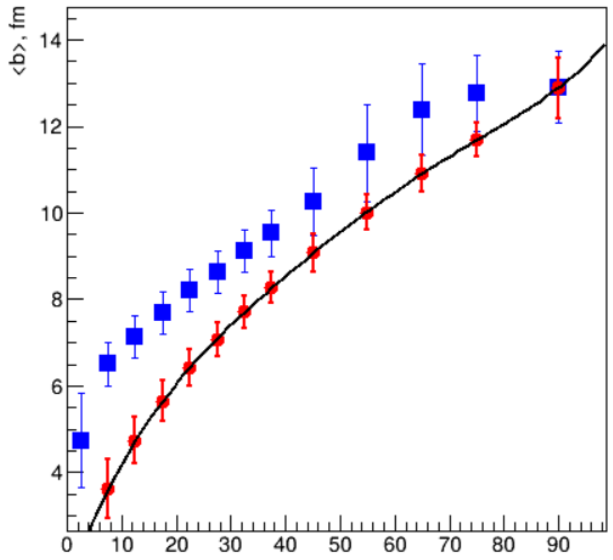
- Via MPD Framework the dependence of impact parameter by centrality classes was obtained (cuts 1);
- MC Glauber fit for prod 35 data is fine.

Prod 35: Results of Gamma-fit



Gamma-fit for data with **cuts 1**

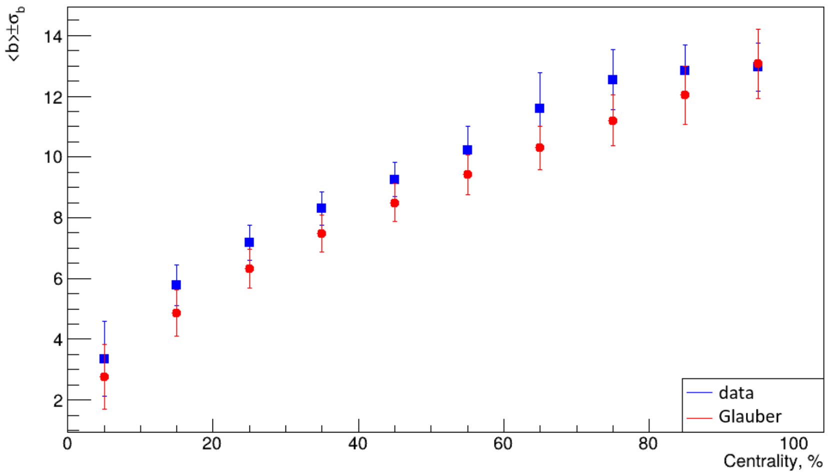
θ = 0.75; N_{knee} = 205.38; a_1 = -3.33; a_2 = 0.08; a_3 = -2.80; χ^2 = 1.16

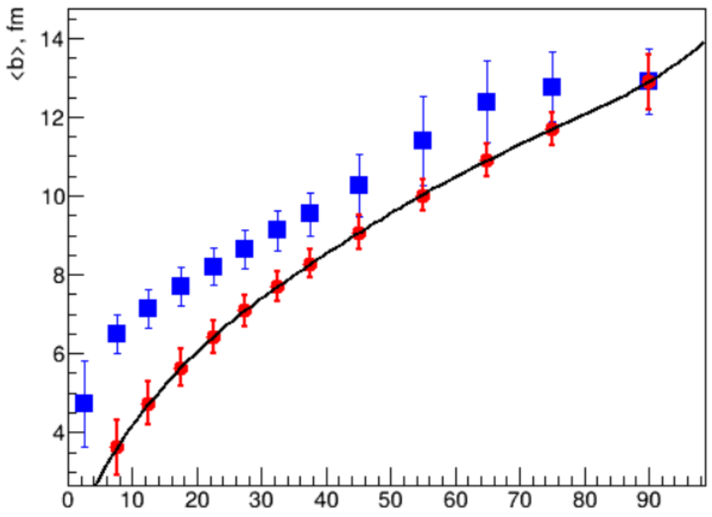


Mean impact parameter vs Centrality for data with **cuts 1**

- Better correspondence of gamma-fit for data with cuts 1 for most central collisions;
- For data with cuts 1 the fit is good for N_{ch} > ~20.

Prod 35: <b> vs Centrality (Gamma-fit vs Glauber)





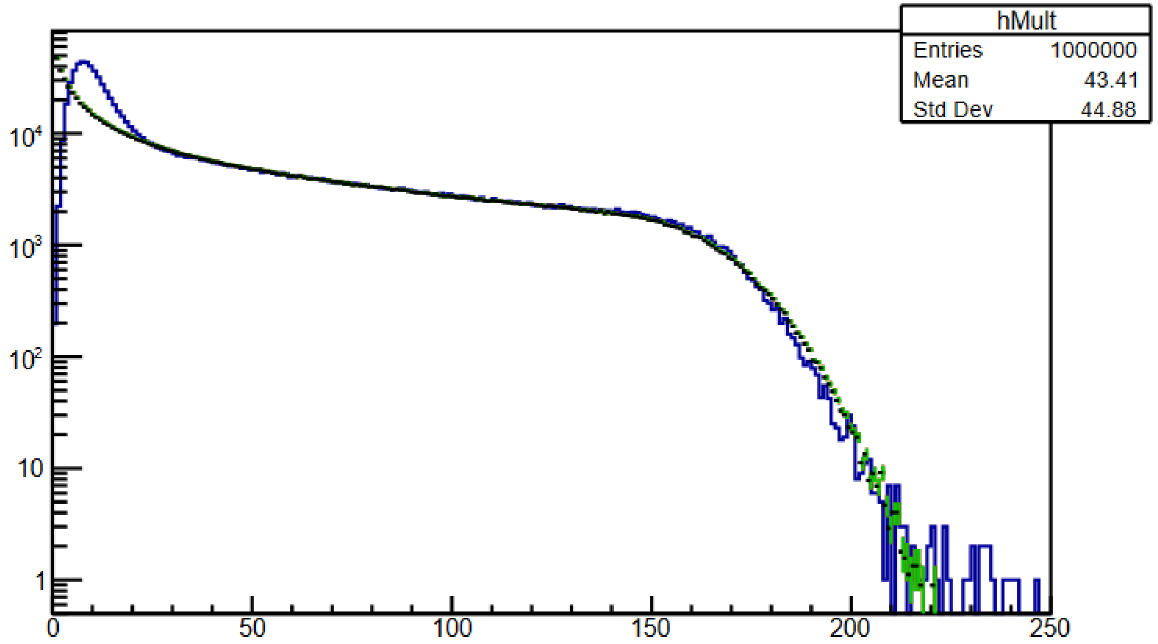
- <b> vs centrality distribution from MC Glauber in good correspondence;
- Gamma-fit results for <b> vs centrality currently have higher deviation from data.

Mean impact parameter vs Centrallity for data with **cuts 1**

Production 36

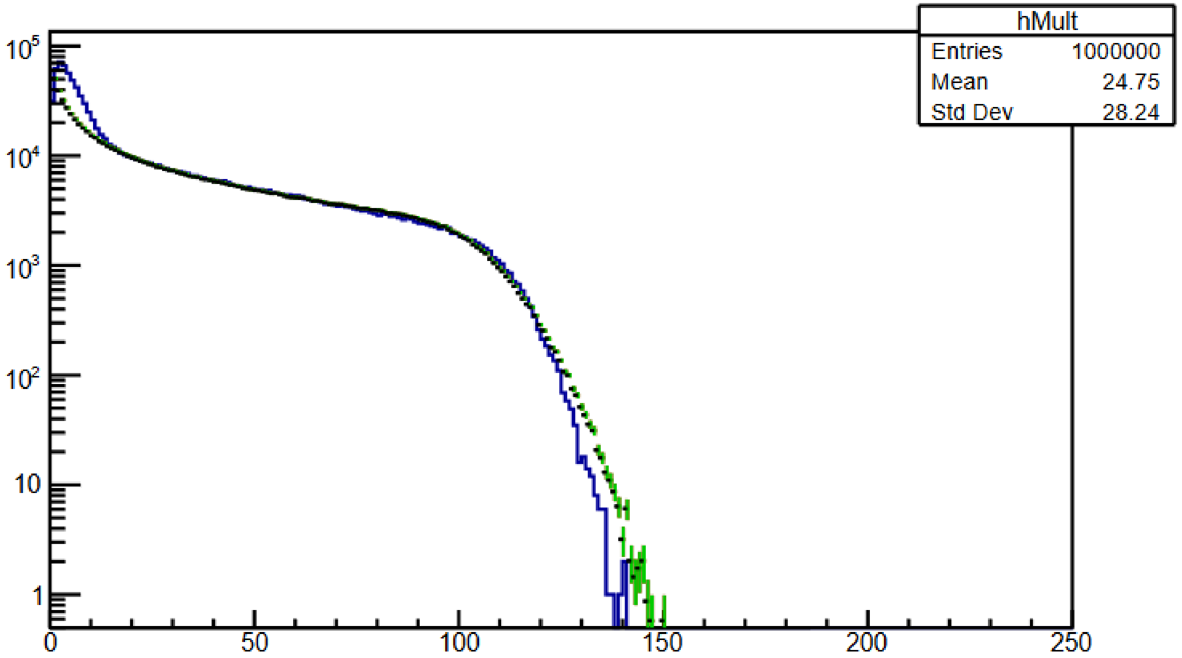
- Prod 36: Xe+Xe, 1M events;
  E_{kin} = 2.5 AGev; $\sqrt{s_{NN}}$ = 2.87 GeV;
- Type of particle is defined via true-PDG value of associated track;
- Used selection criteria:
  - **Cuts 1: 0 < η < 2; Charge ≠ 0;**
  - **Cuts 2: 0 < η < 2; Charge ≠ 0; pT>0,2 GeV/c; Nhits>16**

prod 36 data based fit results for MC



Histogram **cuts 1**. Fit parameters:

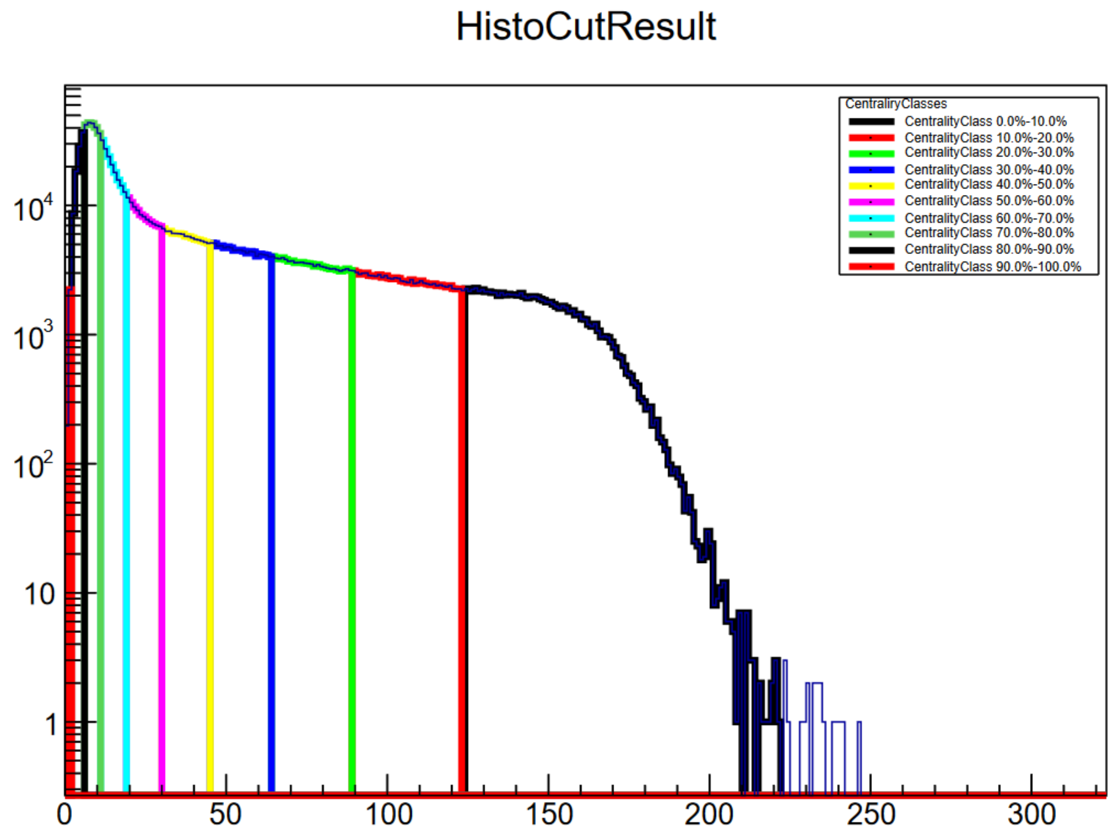
$\mu = 0.73, f = 0.9, k = 60, \chi^2 = 3.212 \pm 0.115$



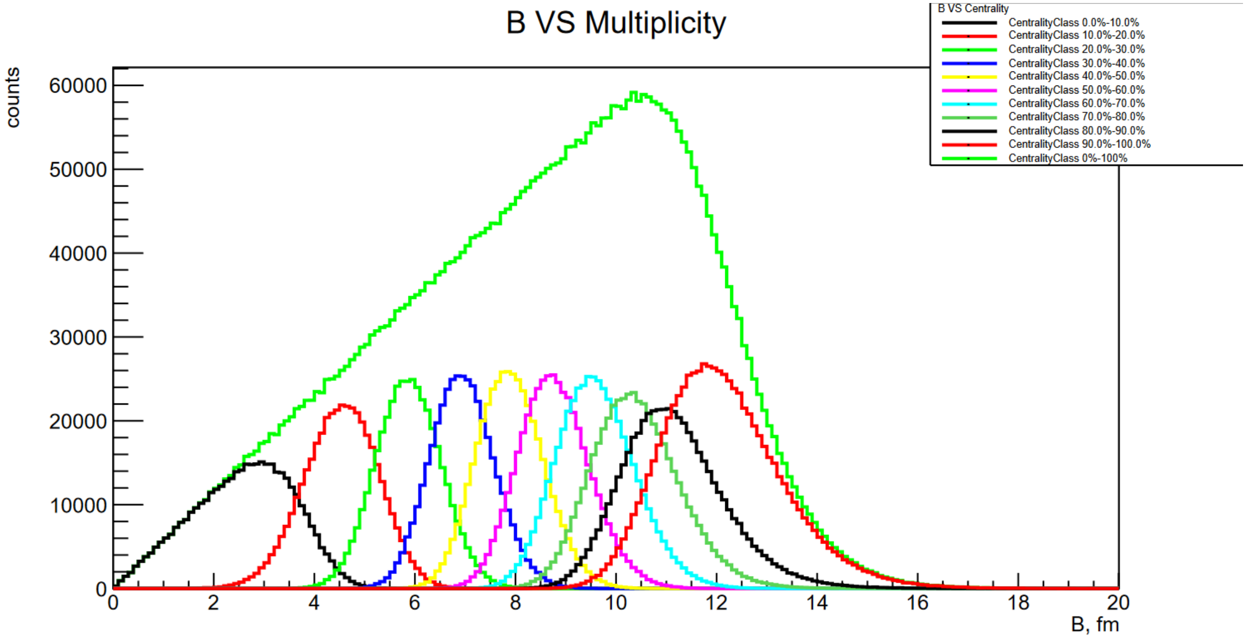
Histogram **cuts 2**. Fit parameters:

$\mu = 0.46, f = 0.9, k = 50, \chi^2 = 6.431 \pm 0.163$

Centrality determination

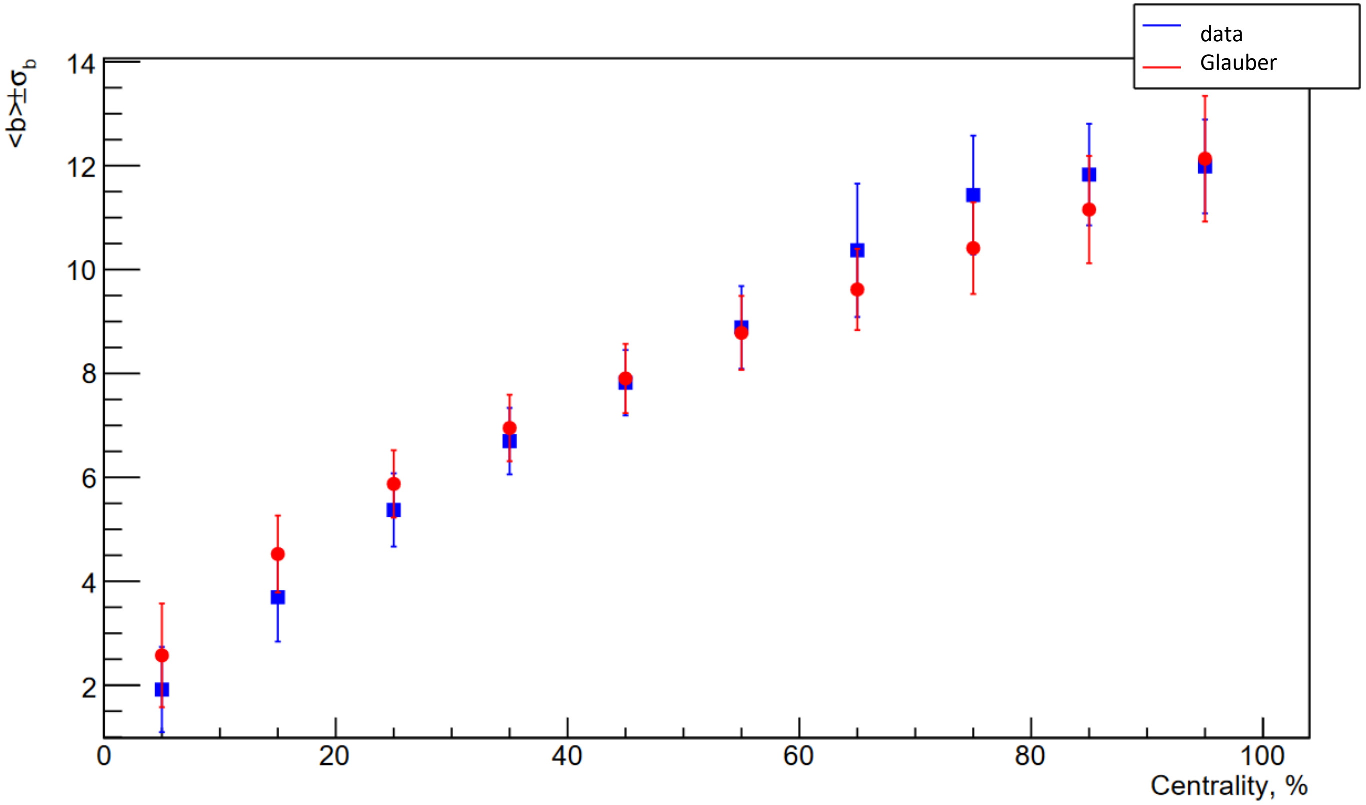


prod 36 Nch histogram with centrality borders from MC



- For centrality classes from MC one can extract connection with B.
- The border between centrality classes is not clear in terms of B.

Impact parameter vs multiplicity



- The dependence of impact parameter on different centrality classes was obtained.
- Data and MC Glauber are in correspondence within errors.

Summary

Prod 35:

- Gamma-fit for prod 35 currently shows better results for data with cuts1 (χ^2 = 1.16 vs χ^2 = 2.815) and provides good agreement for most central collisions;
- However, <b> vs centrality is in better correspondence with data for MC Glauber model;

Prod 36:

- The fit for histograms with cuts converges worse $(\chi^2 = 6.4)$ than histograms without cuts $(\chi^2 = 3.2)$.
- Efficiency plots can be used to estimate registration efficiency for particles with different types, pT and rapidity.
- Based on Nch fit for prod 36 the distributions of B, Ncoll and Npart for different centrality classes were extracted.

All in all:

- Further analysis of both methods for prod 35 and 36 data is needed

First results on centrality determination in Xe+W and Xe+Xe collisions at E_{kin} =2.5 AGeV with MPD-FXT

Production 35 & 36

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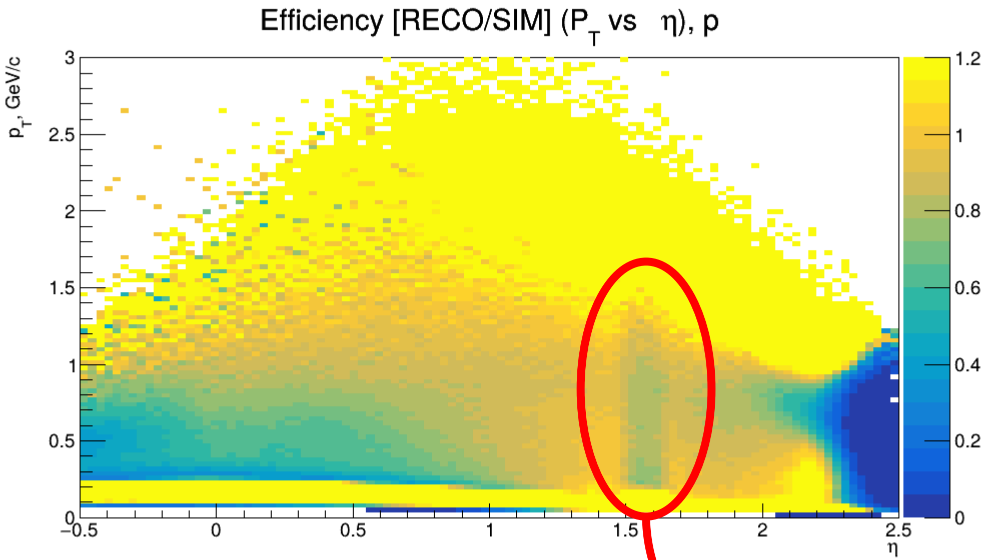
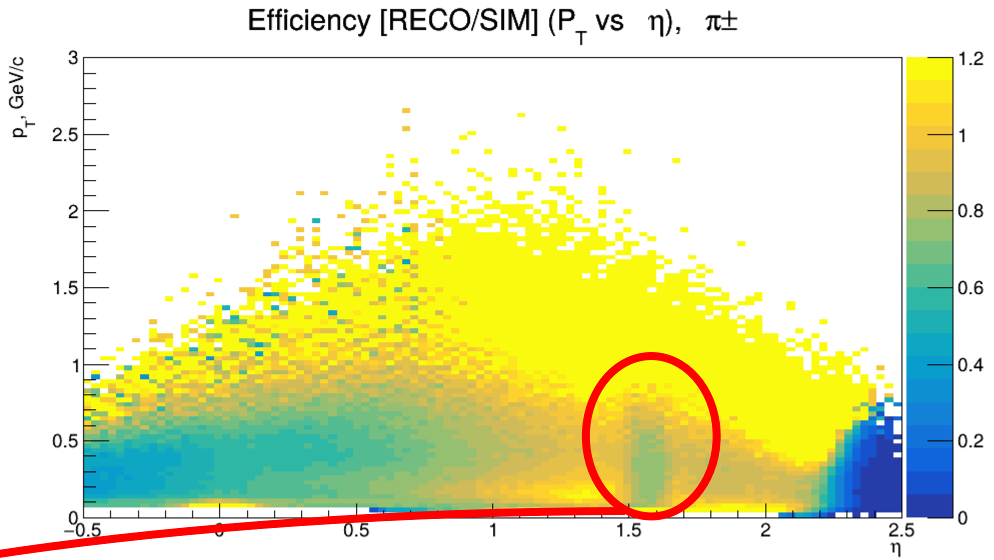
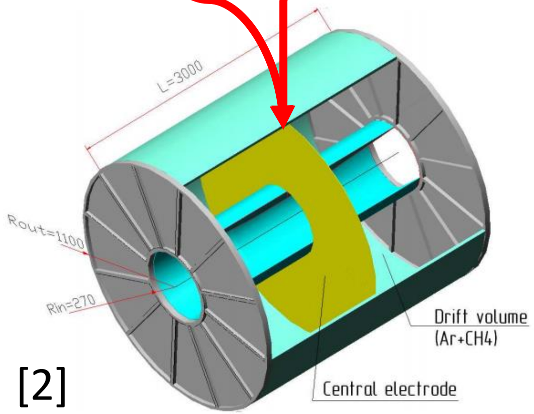
Backup

Prod 35: Efficiency: P_T vs Pseudorapidity

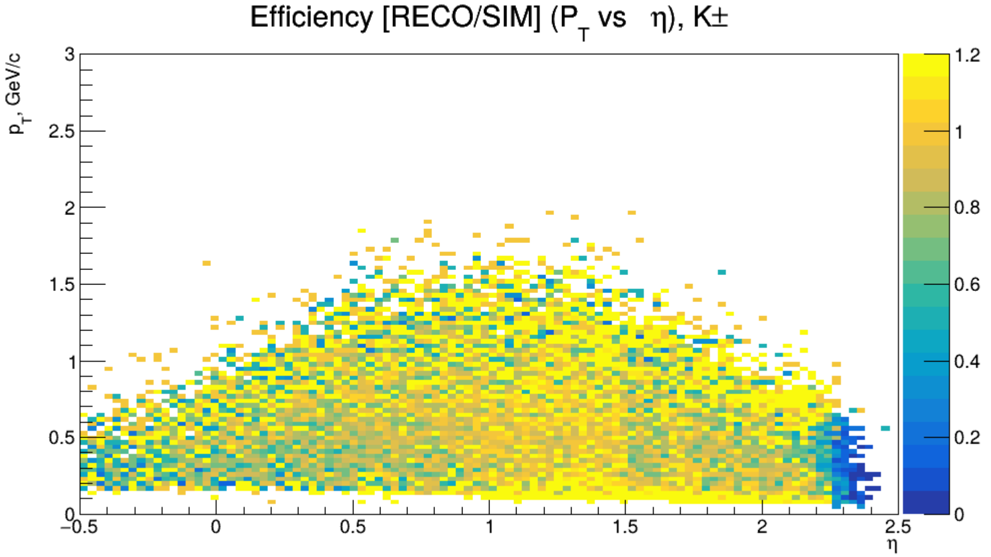




- Efficiency was calculated as ratio between reconstructed and simulated data;
- Slight minimum in P_t distribution over η observed only in reconstructed tracks;
- Might be due to TPC central electrode position;

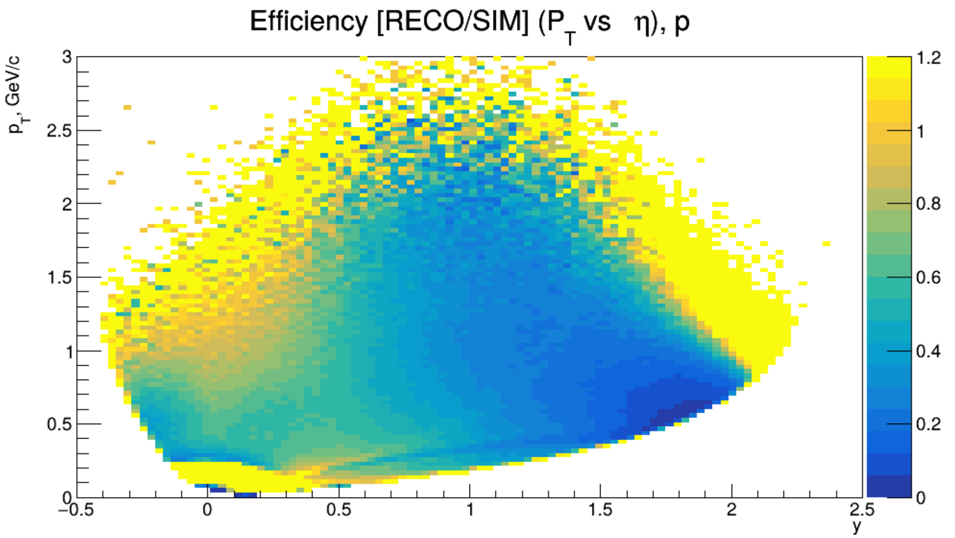


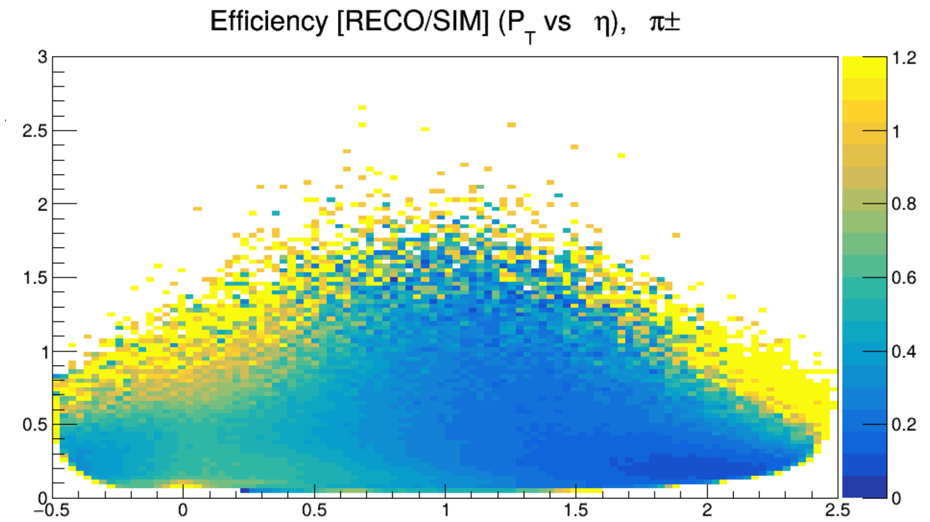
[2]

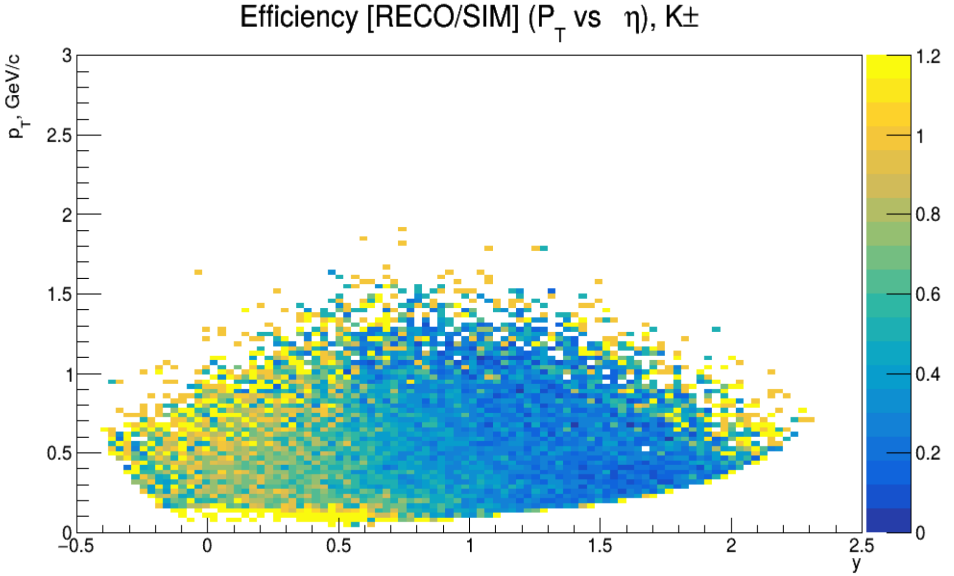


[2] - NICA online site (MPD section): https://nica.jinr.ru/ru/projects/mpd.php

Prod 35: Efficiency: P_T vs Rapidity



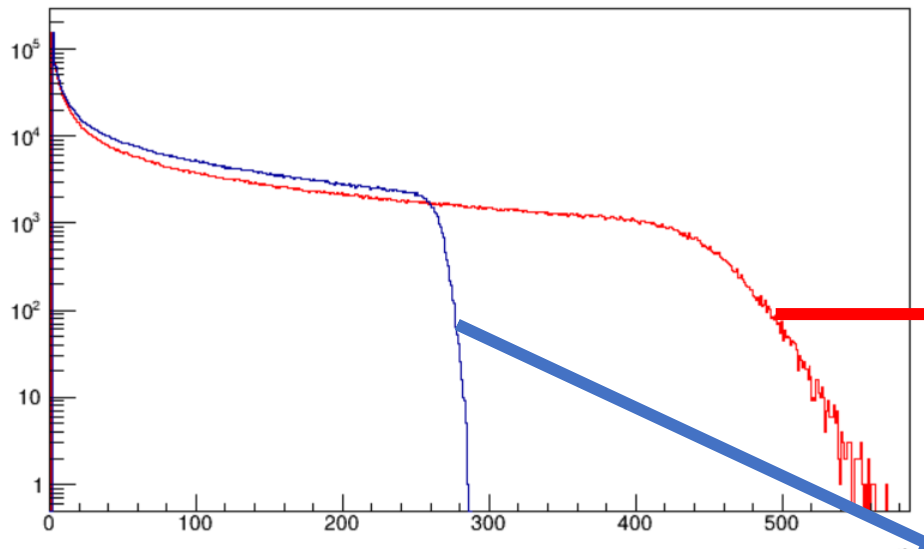




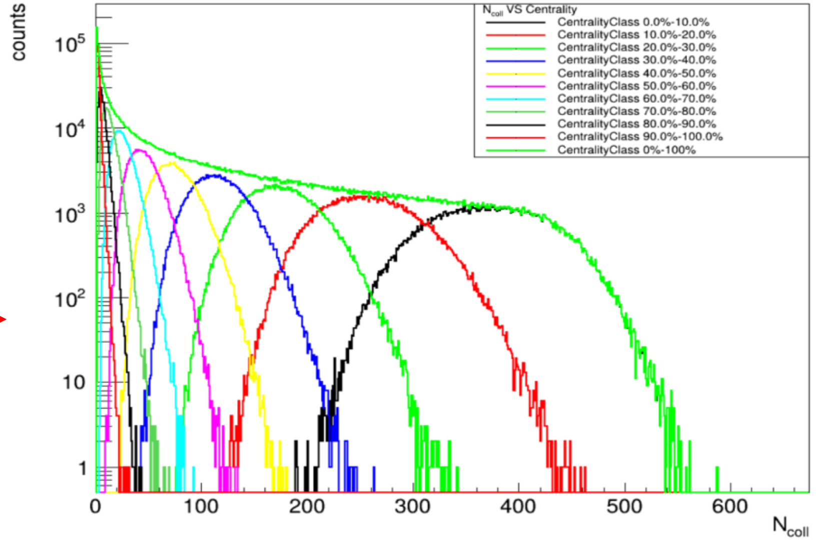
- For reconstructed tracks rapidity was calculated from data as:

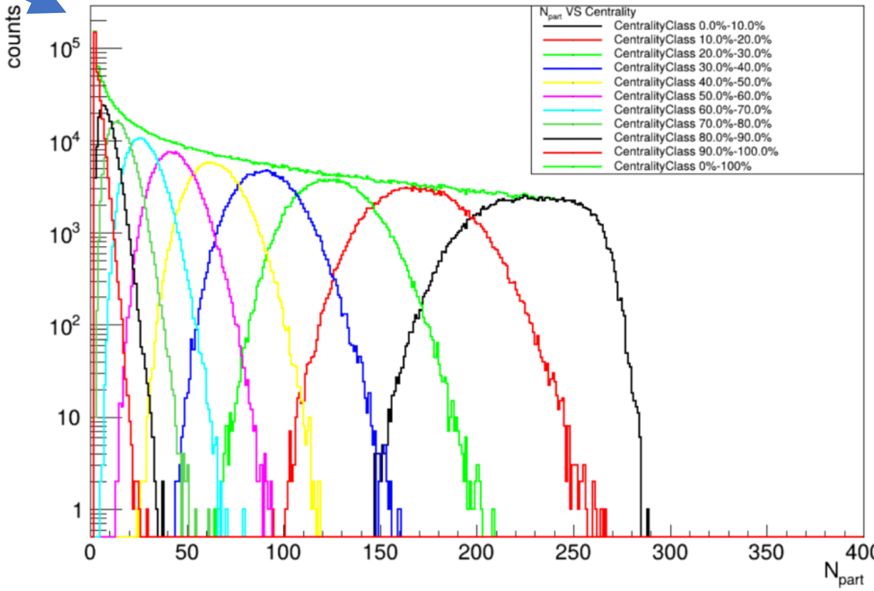
$$y = 0.5 \log\left(\frac{E + p_z}{E - p_z}\right), \text{where } E = \sqrt{m^2 + p_T^2}$$

Prod 35: Npart and Ncoll in centrality classes



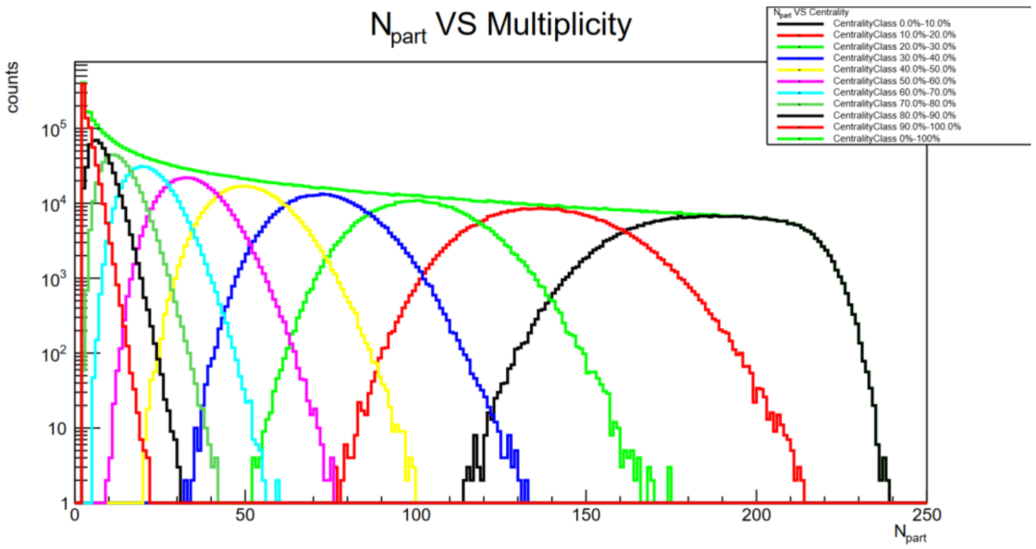
Npart (blue) and Ncoll (red) distribution

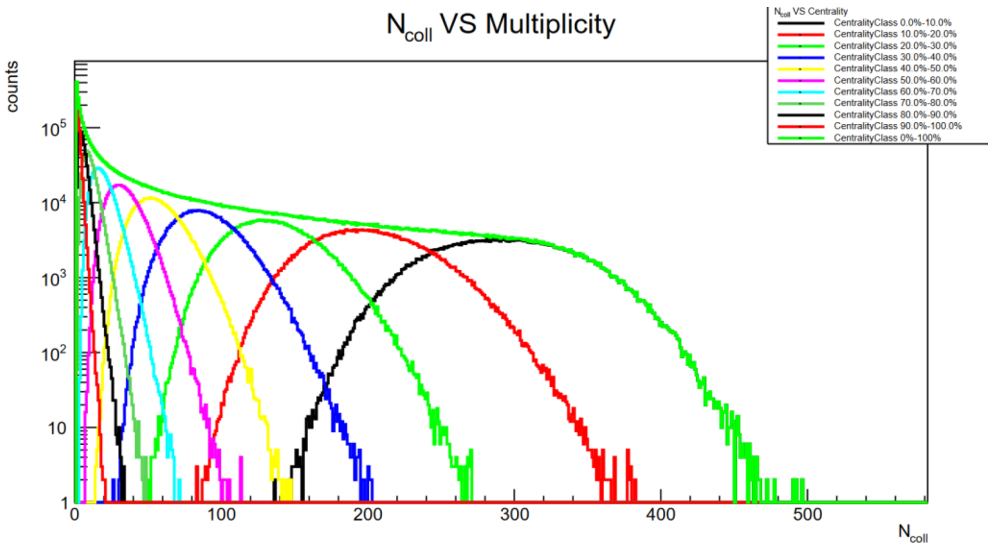




- Number of collisions and participant nucleons are divided into centrality classes as well

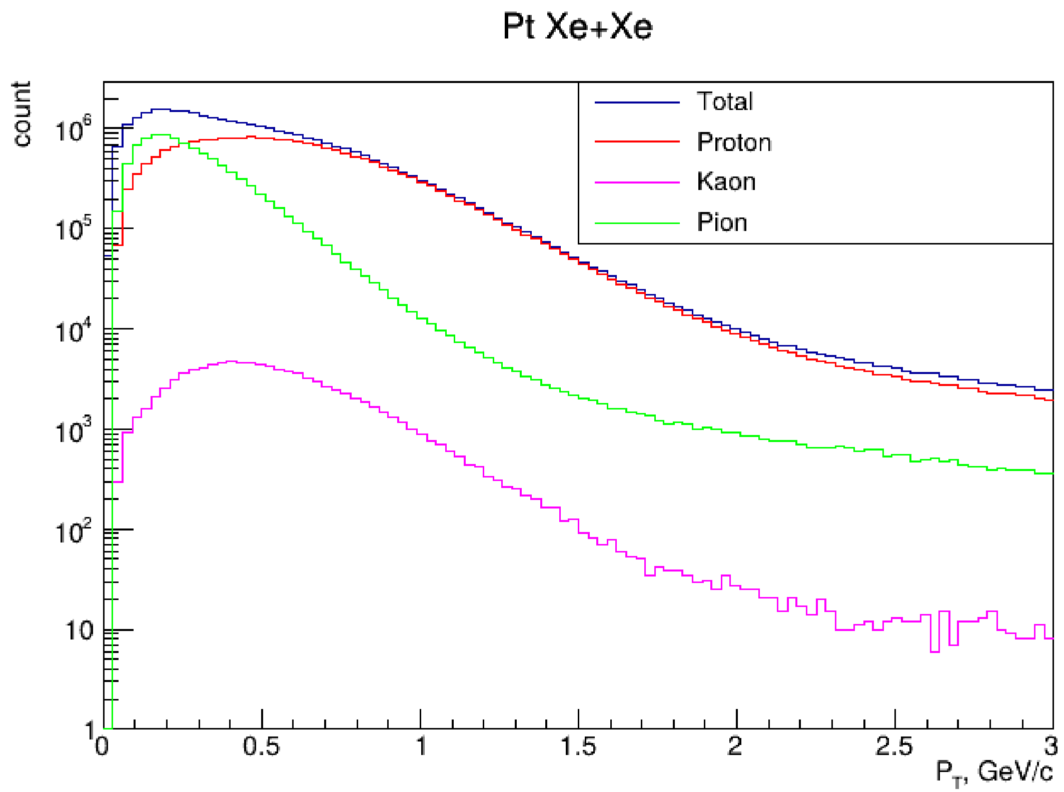
Npart, Ncoll in centrality classes prod 36



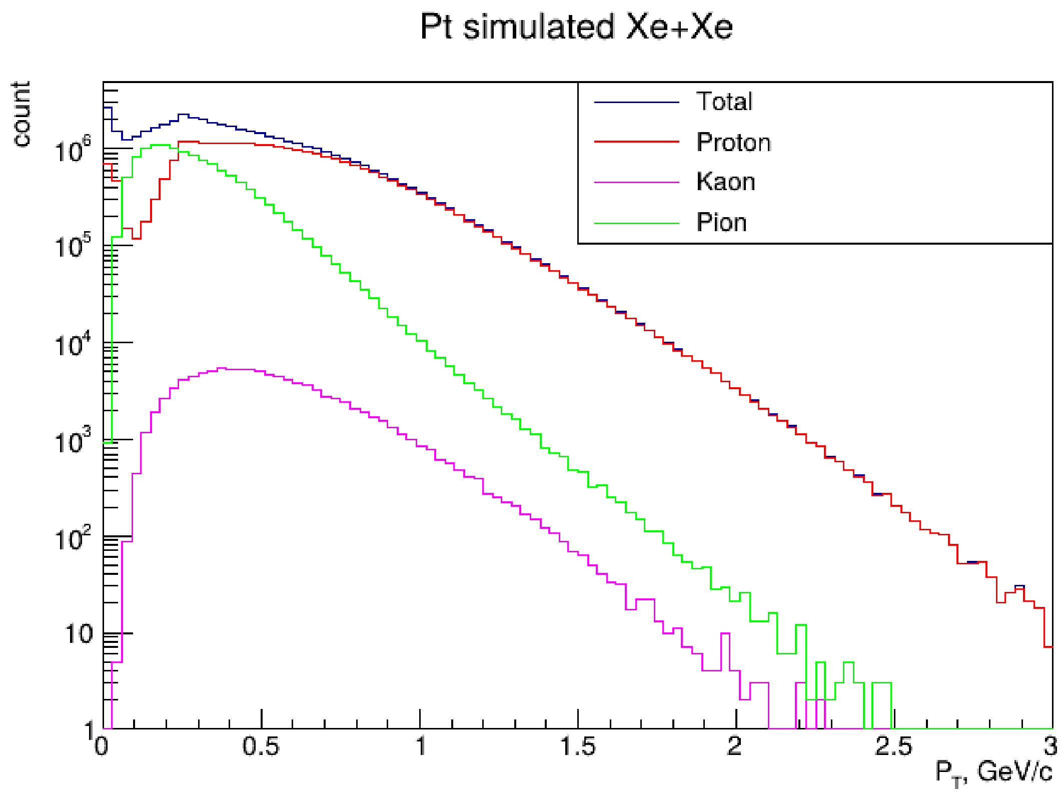


- The same way one can determine number of collision and participants for centrality classes.
- These quantities can be obtained only from MC.
- The same way there is no clear border between centrality classes.

Prod 36



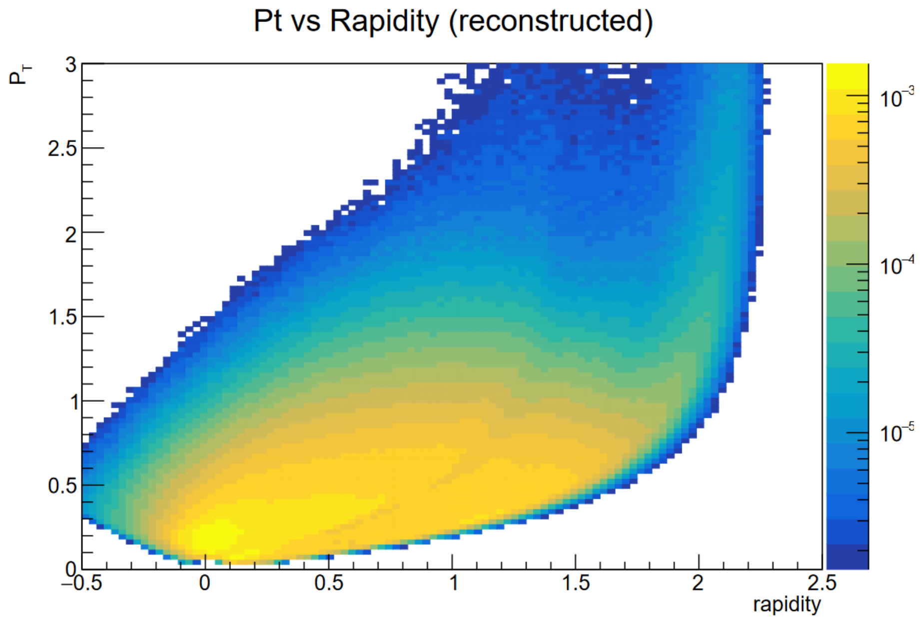
Reconstructed data from GEANT4 for Xe-Xe collision



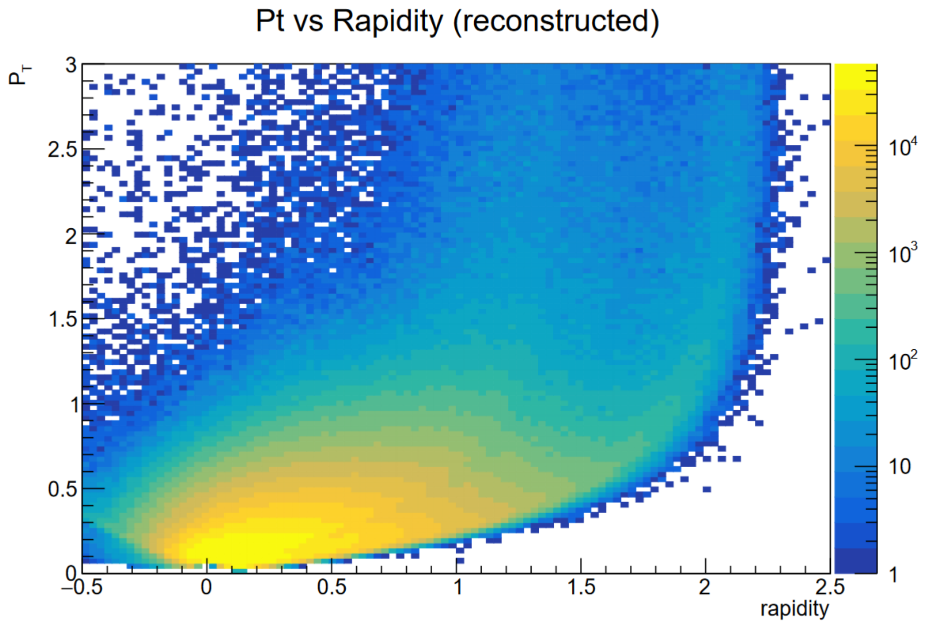
Simulated data from UrQMD for Xe-Xe collision

Pt vs rapidity prod 36

- The rapidity vs Pt plots may be used for identification of particles.
- The position of right border depends on particle rest mass.

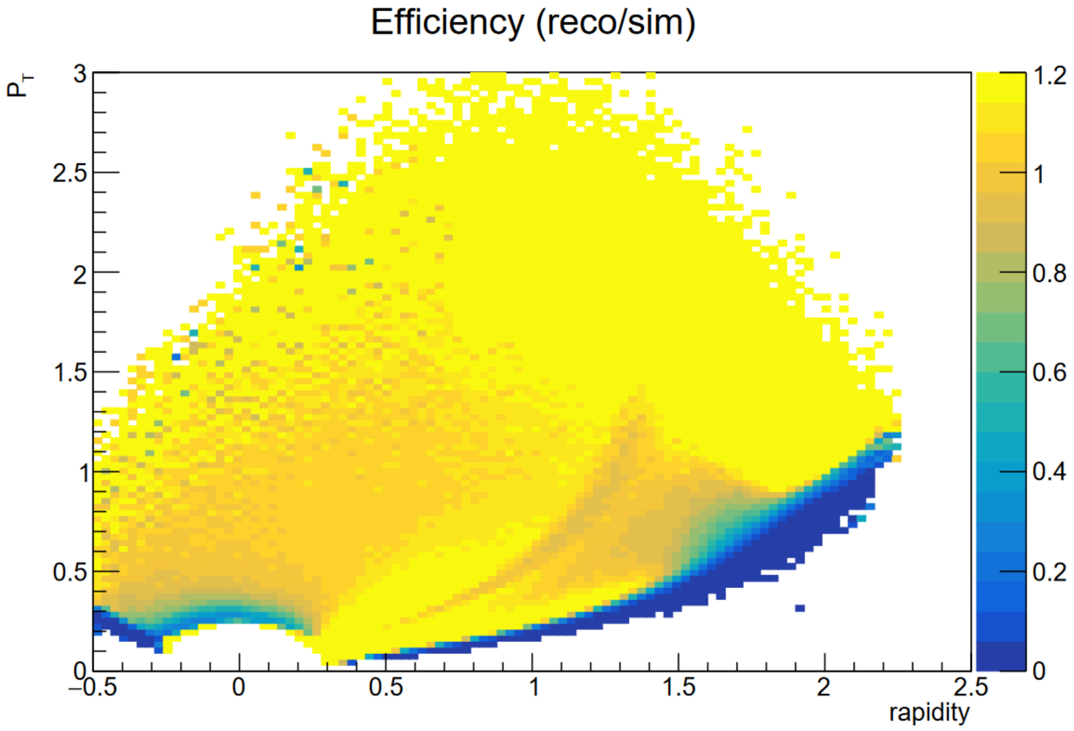


Reconstructed data for protons

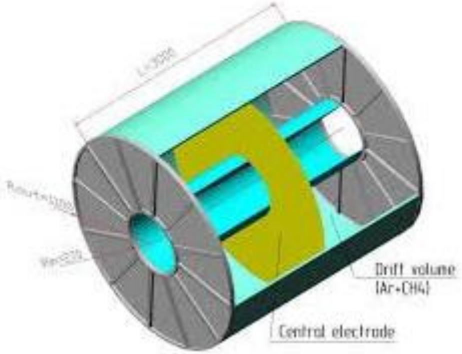


Reconstructed data for pions

Efficiency for primary proton prod 36



- At 90 degrees central electrode prevents detection of events.
- Tracks at midrapidity are registered with the highest efficiency.
- Detector geometry affects the registration efficiency.



Gamma vs Glauber vs Data