Centrality determination in CBM at FAIR

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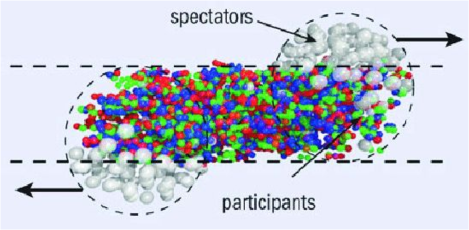
Motivation

- Evolution of matter produced in heavy-ion collisions depends on its initial geometry
- Model quantities: impact parameter, number of participants, number of binary collisions, etc
- Measurable: multiplicity of produced charged particles, energy of spectators, their combination, etc
- Goal: relate on average model and measurable quantities

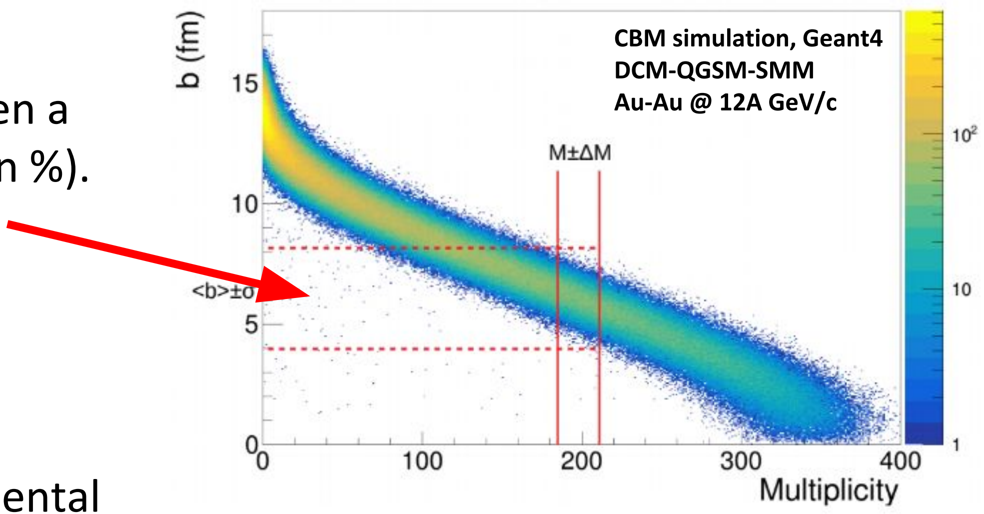


Centrality definition

- <u>Centrality class</u>:
  group of events corresponding to a given a fraction of the total cross section σ_{AA} (in %). It is related to the range of impact parameter values

$$C_b = \frac{1}{\sigma_{AA}} \int_b^{\infty} \frac{d\sigma}{db'} db'$$

- Mapping collision geometry to experimental observables



Anticorrelation between impact parameter and multiplicity allows to quantify initial geometry parameters

How to map model quantities and centrality estimators?

- Initial geometry of collision is given by MC Glauber model and corresponding number of ancestors

- Final state distribution of particles (result of the matter evolution) is mapped to the initial state parameters via known distributions for NN interaction (E.g.: NBD(μ, k), which models production of charged particles)

- This mapping provides connection between parameters from Glauber model and distributions of centrality estimators (e.g. from signals in the CBM detector). Free model parameters are fixed by finding the best description of the distributions of centrality estimators.

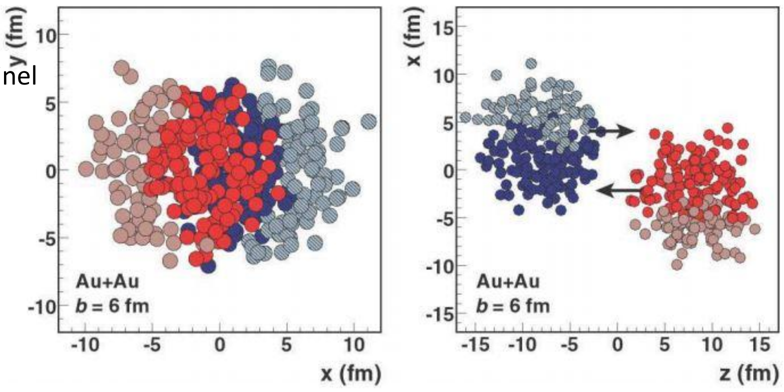
MC Glauber model

MC Glauber model provides a description of the initial state of a heavy-ion collision

- Main ideas:
  - Independent straight line trajectories of the nucleons
  - A nucleus-nucleus collision is treated as a sequence of independent binary nucleon-nucleon collisions
  - Position of nucleons in individual collision are sampled using Monte-Carlo simulation

<u>Main configuration parameters</u>:

- Collision system
- Inelastic nucleon-nucleon cross section, σ^{NN}_{inel} (depends on collision energy)
- Nuclear charge densities Wood-Saxon distribution: $\rho(r) = \rho_0 \cdot \frac{1 + w(r/R)^2}{1 + \exp\left(\frac{r-R}{a}\right)}$



Glauber Modeling in High Energy Nuclear Collisions: Ann.Rev.Nucl.Part.Sci.57:205-243,2007

<u>Geometry parameters</u>:

b – impact parameter

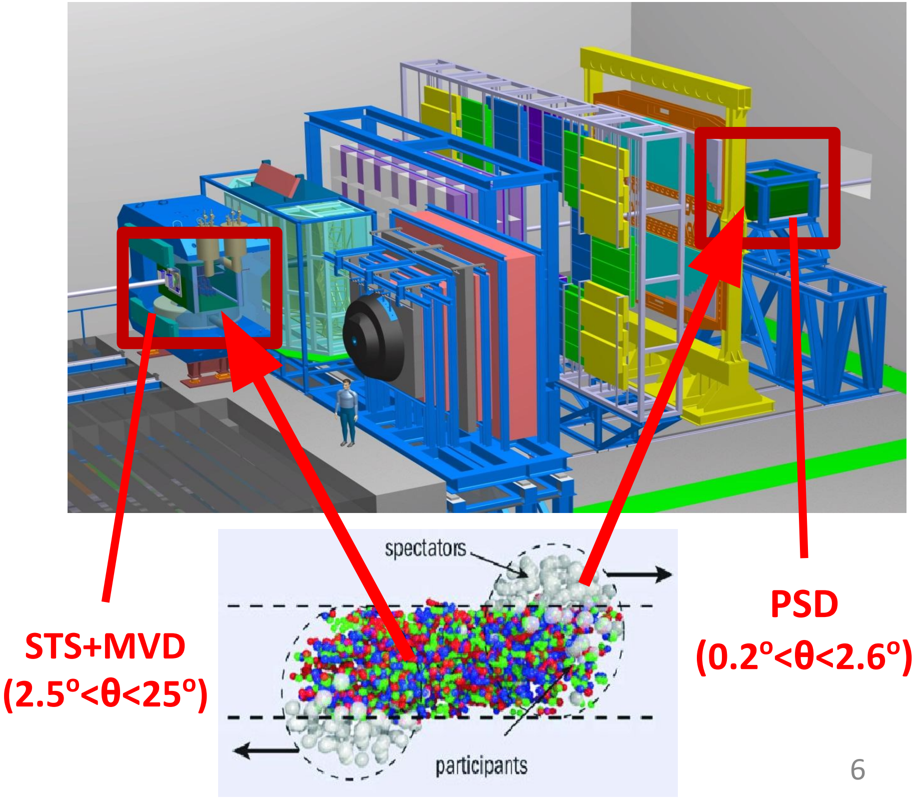
N_{part} – number of nucleons participating in the collision

N_{spec} – number of spectator nucleons in the collision

N_{coll} – number of binary NN collisions

CBM experiment and subsystems for centrality determination

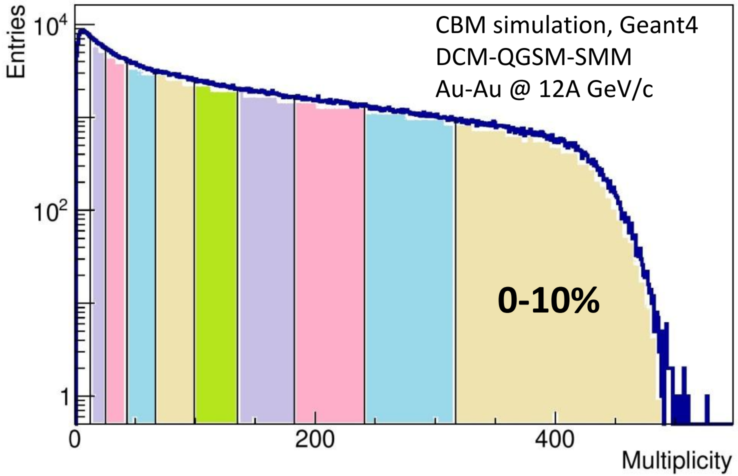
- FAIR
  Facility for Antiproton and Ion Research, Darmstadt, Germany
- CBM@FAIR - Compressed Baryonic Matter
  - Type: fixed-target
- Simulation setup:
  - UrQMD or DCM-QGSM-SMM
  - Reconstructed with GEANT4
  - Au-Au @ p_{beam} = 12A GeV/c
  - Tracking system: MVD+STS
  - PSD geometry 20 cm hole size, 44 modules



Centrality determination with multiplicity

$$C_N = \frac{1}{\sigma_{AA}} \int_{N_{thr}}^{\infty} \frac{d\sigma}{dN'} dN'$$

Produced charged particles



MC Glauber fitting procedure

Input multiplicity distribution

N_{part}, N_{coll} from Glauber Model

Evaluate ancestors* number

$N_a = f\, N_{part} + (1-f)\, N_{coll}$

Sample N_a times the number of produces particles with NBD(μ, k)

Build multiplicity distribution for fitting

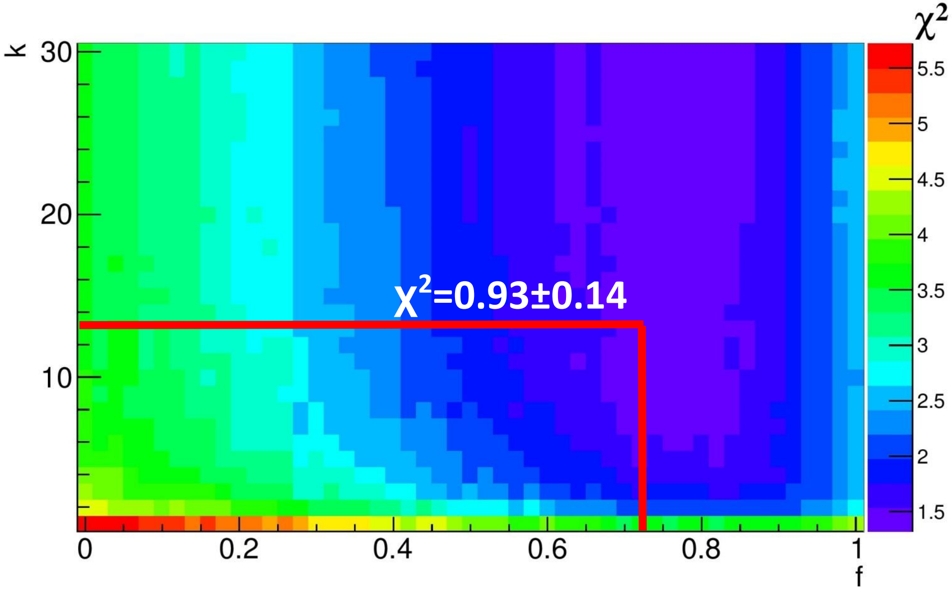
Evaluate χ^2

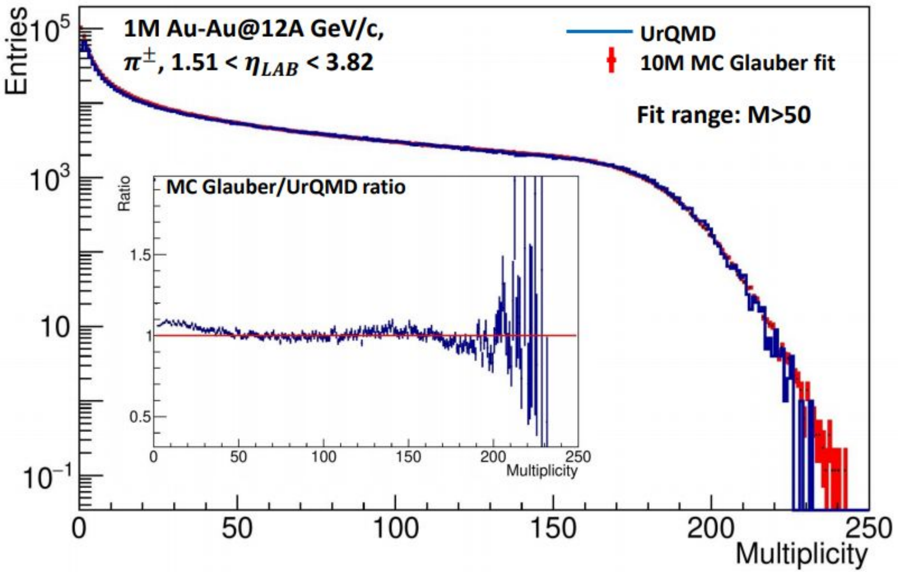
Minimize χ^2 to find f, μ and k

Extract relation between geometry parameters and multiplicity

*ancestors: sources of produced particles

Fit results for the UrQMD multiplicity distribution



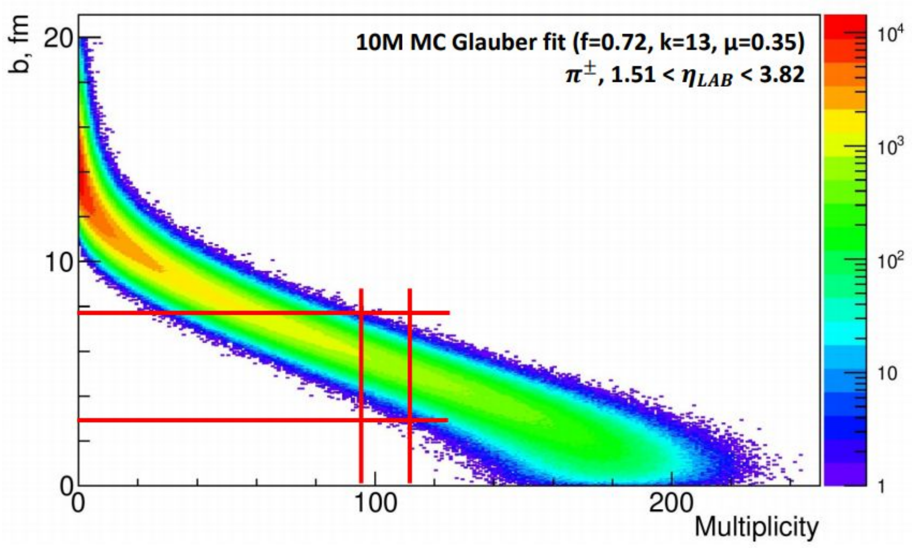


Scan the phase space of (f, k) to find a value of μ with minimal χ^2

fit:
f=0.72, μ=0.35, k=13

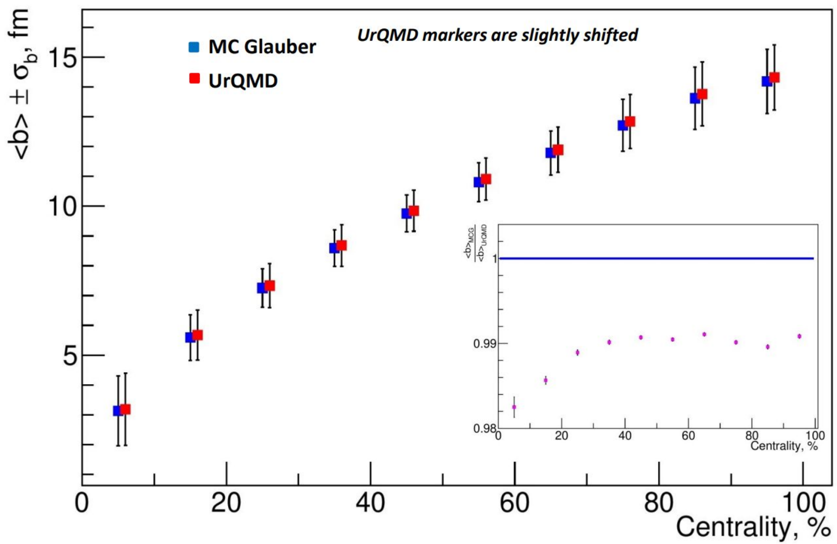
MC Glauber fit reproduces multiplicity distribution of produced charged particles simulated with the UrQMD

Impact parameter vs. multiplicity



Distribution provides connection between a centrality class (multiplicity range, M ± ΔM) and impact parameter range (b ± σ_b)

Average impact parameter and its width



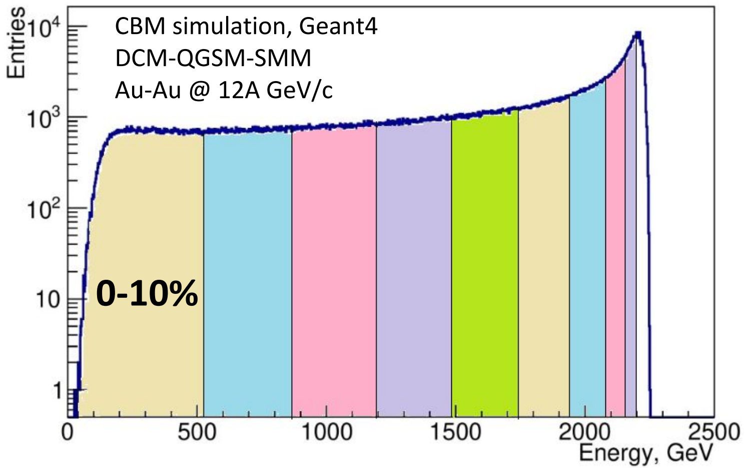
Agreement within 1-2% between UrQMD and MC Glauber fit

Centrality determination with Spectators (PSD Energy)*

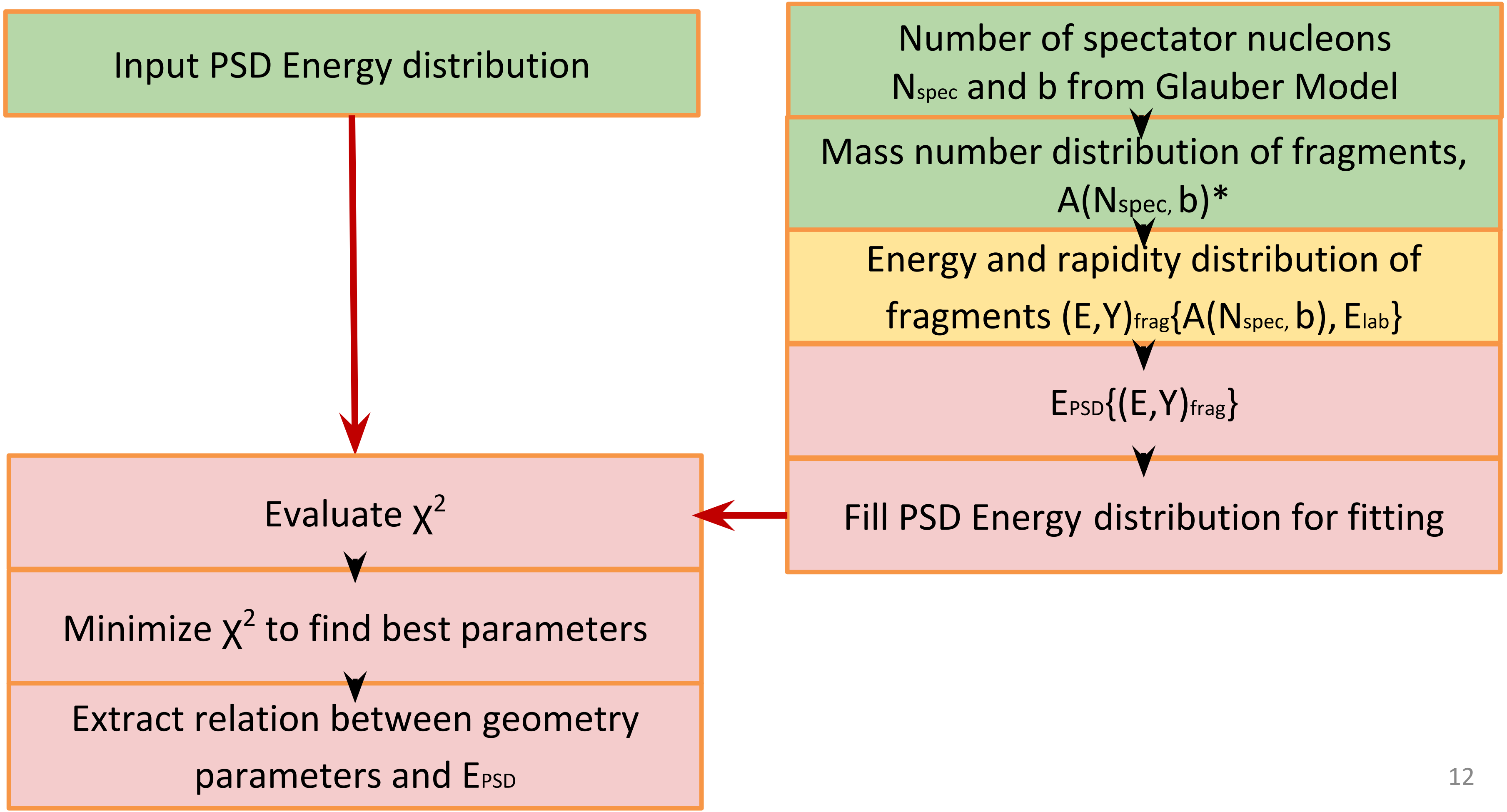
* work in progress

$$C_E = \frac{1}{\sigma_{AA}} \int_0^{E_{thr}} \frac{d\sigma}{dE'} dE'$$

Spectators

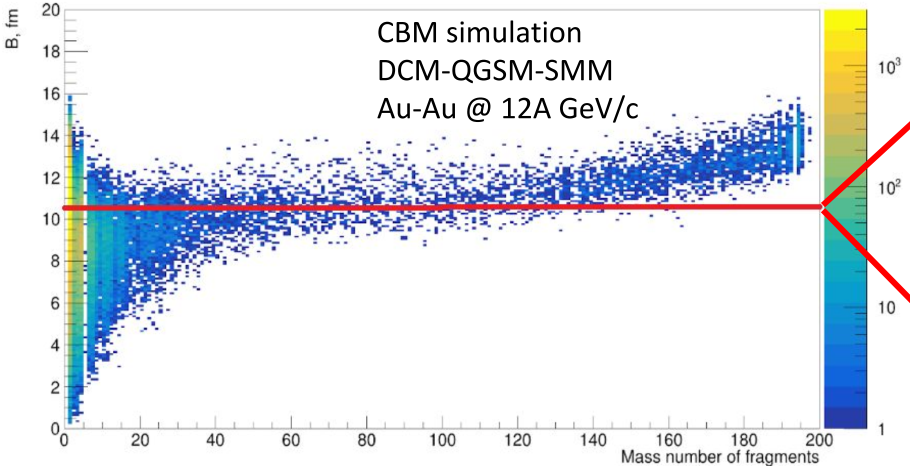


Procedure for centrality determination with PSD energy

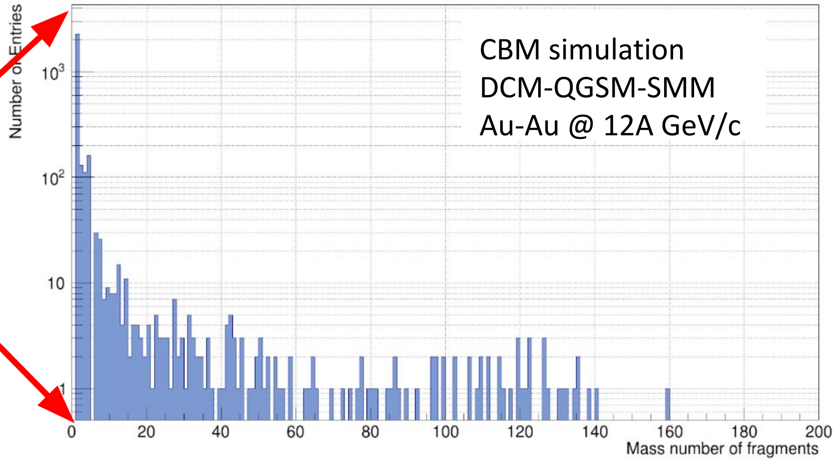


Mass number distribution of fragments for a given impact parameter value

2D distribution of impact parameter and fragment's mass number

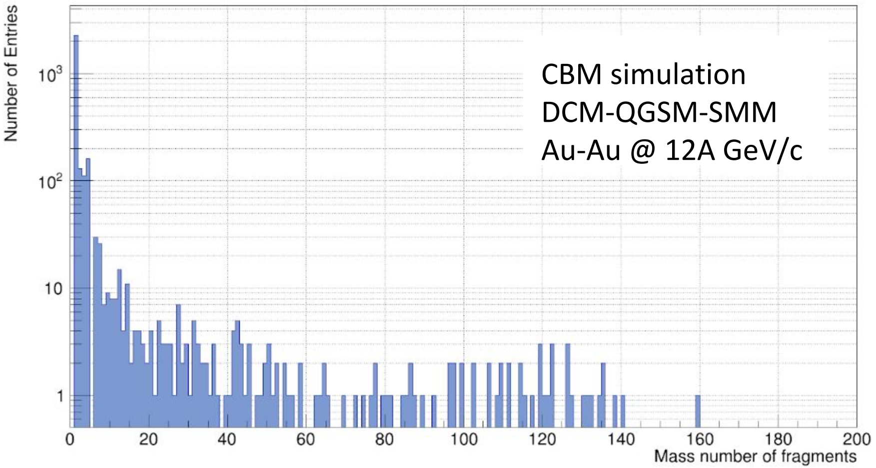


Projection for a given impact parameter using N_{spec} from MC Glauber

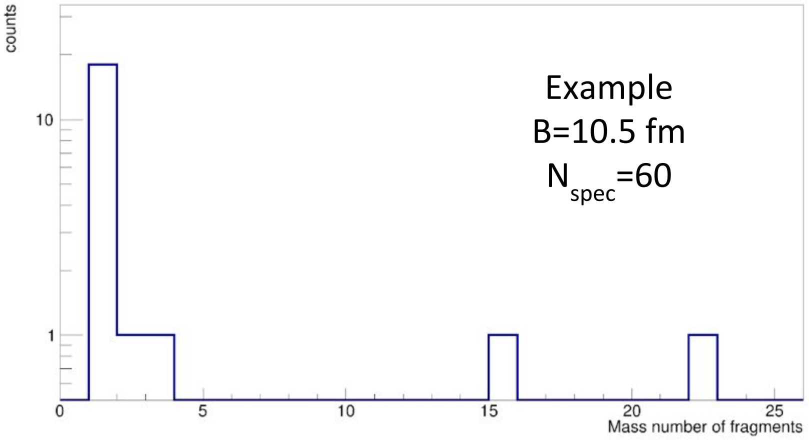


Mass number distribution of fragments for a given collision

Projection for a given impact parameter using N_{spec} from MC Glauber



Mass number distribution of fragments for a single MC Glauber event

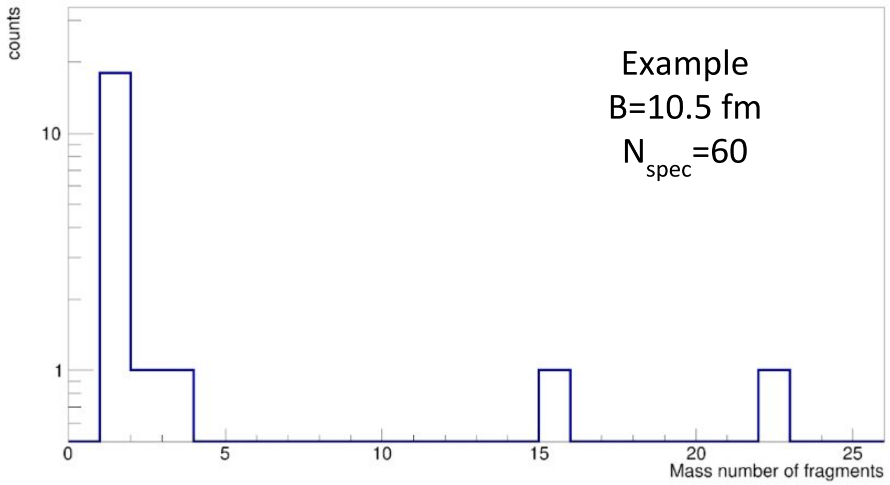


Procedure to generate fragment's mass number distribution for a given collision:

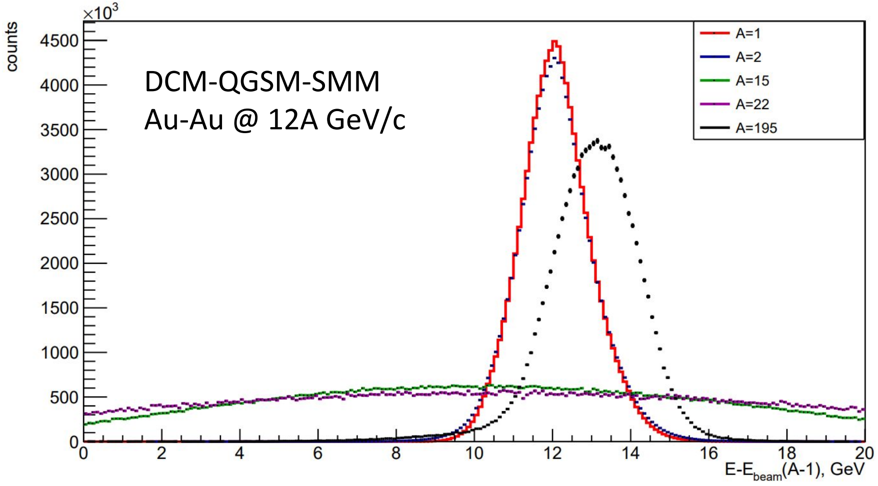
1. a. Generated a fragment mass number A_1
   b. if { $N_{spec} < A_1$} { then skip and do step #1.a again } else { $N'_{spec} = N_{spec} - A_1$}
2. Repeat Step #1 while $N_{spec'} > 0$
3. Result: $N_{spec} = A_1 + A_2 + ... A_N$

Population of fragments with energy and rapidity

Mass number distribution of fragments for a single MC Glauber event



Energy distributions of different fragments (shifted to beam energy)



Currently working on implementing:
assign to each fragment a value of energy and rapidity using DCM-QGSM model
(same approach as for mass number distribution sampling)

Summary

- MC Glauber fitting procedure is developed for multiplicity estimators:
  - Extracted relation between impact parameter and centrality classes
  - Software implementation of the procedure is used also in (Code repository: *https://git.cbm.gsi.de/pwg-c2f/analysis/centrality*):
    - MPD @ NICA studies
    - HADES and NA61/SHINE (ongoing work)
- Procedure for centrality determination using spectator's energy is proposed:
  - Implemented: generation of the fragment's mass number distribution (tuned to the output of the DCM-QGSM-SMM model simulations)
  - In progress: sampling energy and rapidity distributions of fragments

Thank you for your attention !

Acknowledgments

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Backup slides

Software: Centrality Framework

MC Glauber based procedure for centrality determination with multiplicity implemented in the Centrality Framework (V. Klochkov and I. Selyuzhenkov):

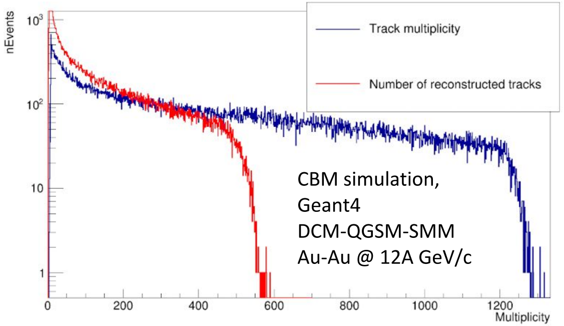
Code repository: *https://git.cbm.gsi.de/pwg-c2f/analysis/centrality*

Viktor Klochkov (Tubingen University)

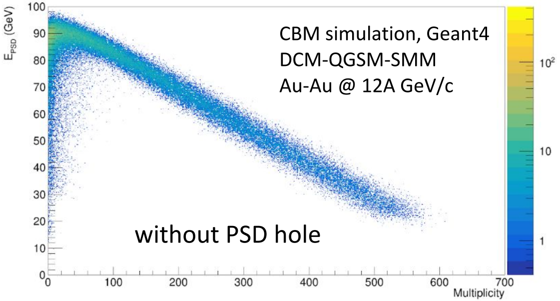
Ilya Selyuzhenkov (GSI / MEPhI)

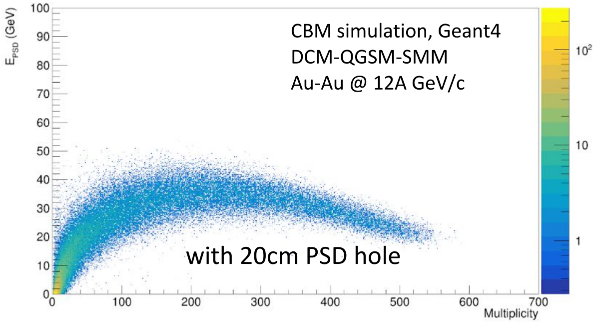
Challenges in working with real data

- Detector efficiency + acceptance (tracking)

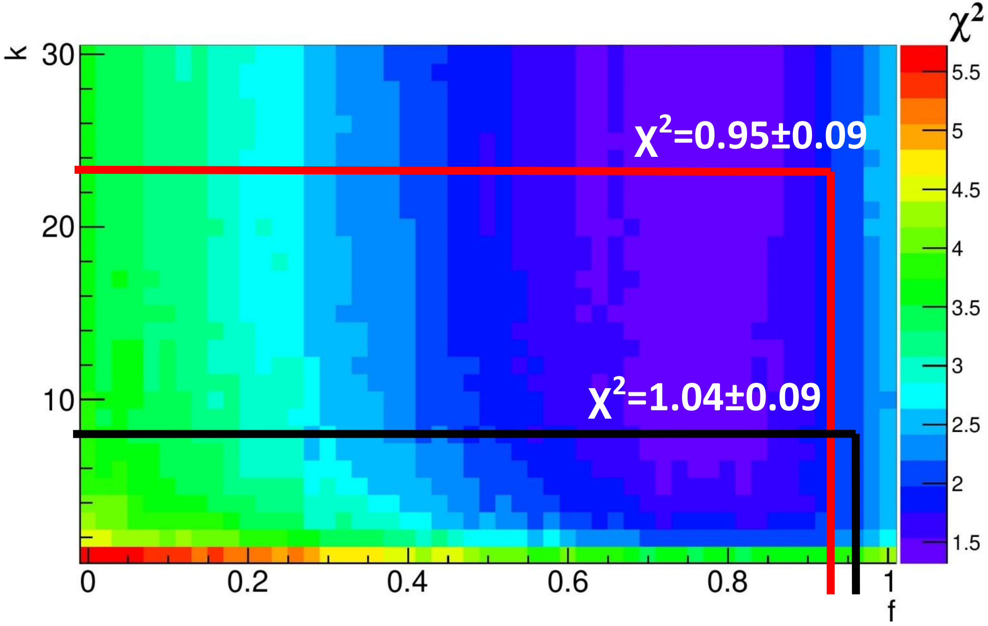


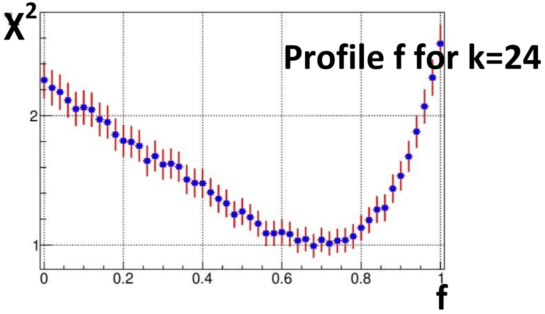
- Detector acceptance (fragment losses)



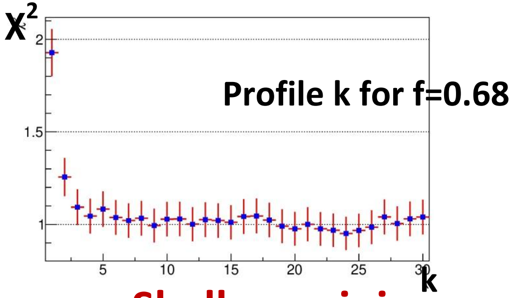


Self-consistency check: search for min χ^2





Clear minimum



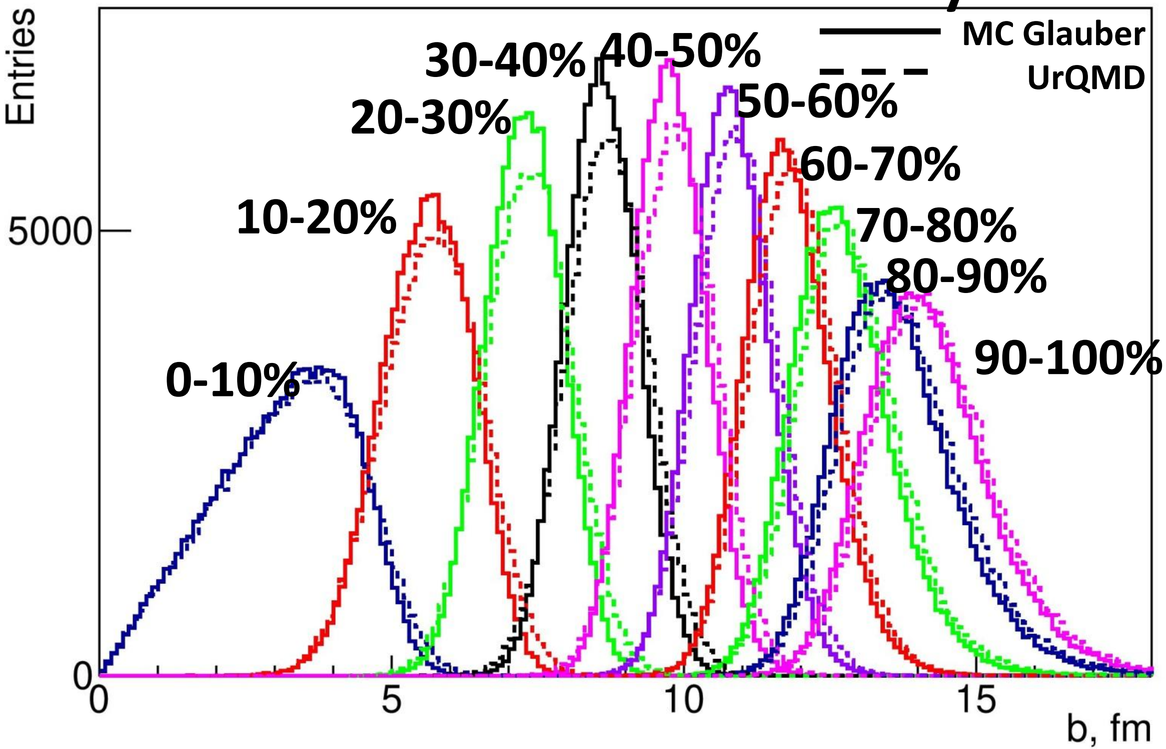
Shallow minimum

For each (f, k) pair optimal (with minimal χ^2) μ is found.

Input:	Output:
f=0.70, μ=0.85, k=9	f=0.68, μ=0.83, k=24

In terms of statistics input and found values of χ^2 are equivalent.

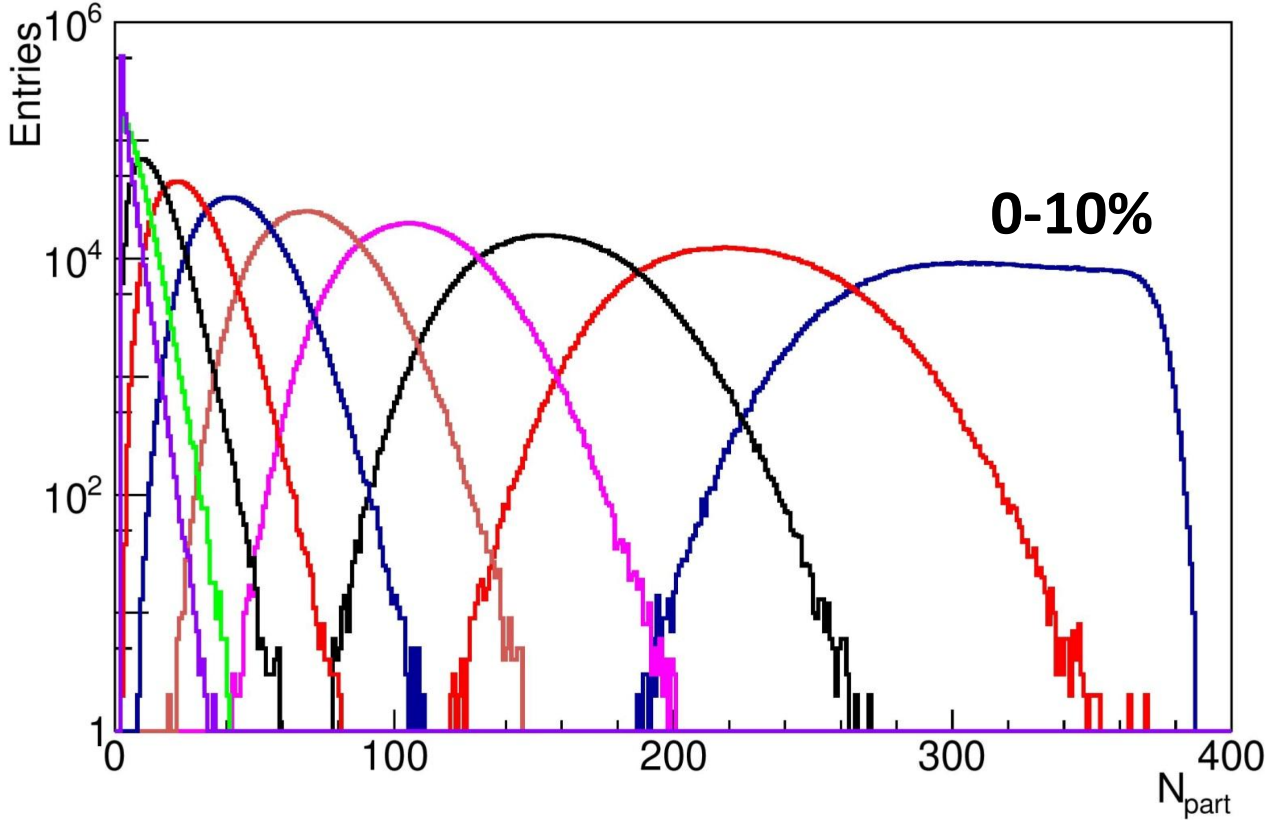
b distribution in centrality classes



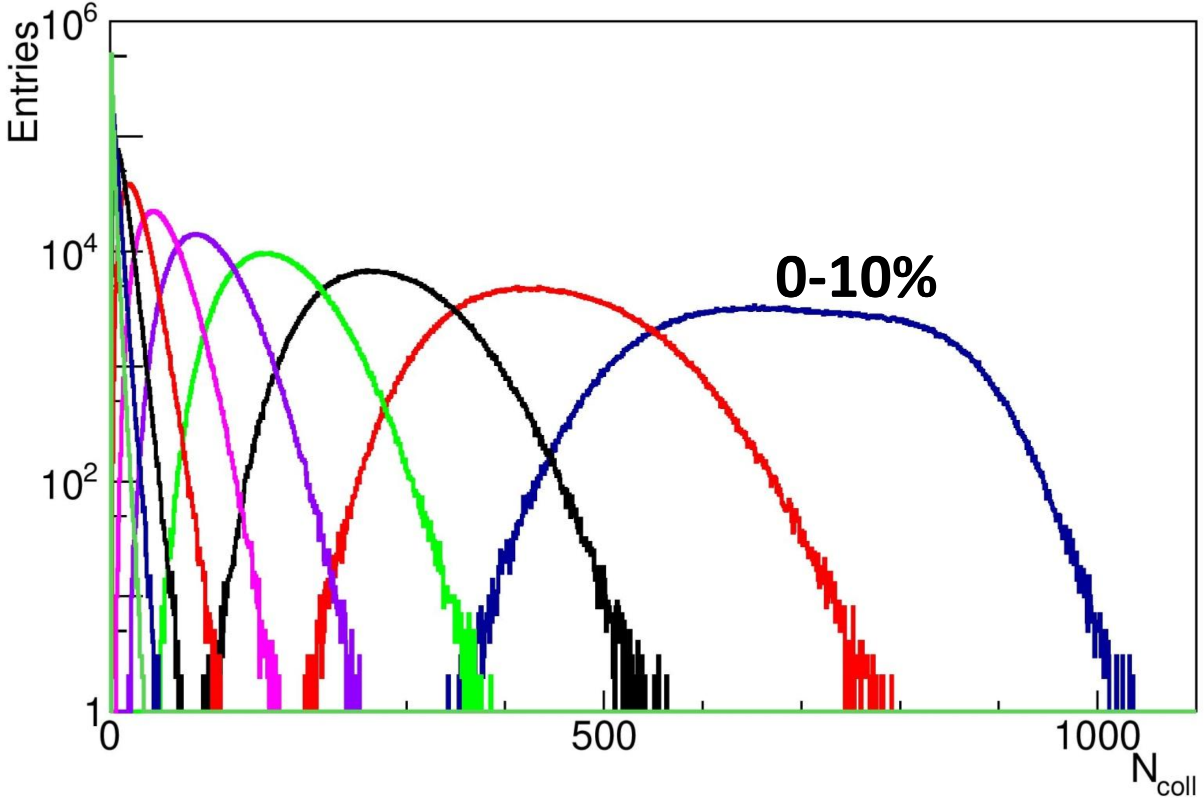
We observe 1-2% difference between MC Glauber fit and UrQMD data.

The same distribution for N_{part} & N_{coll} is available in backup

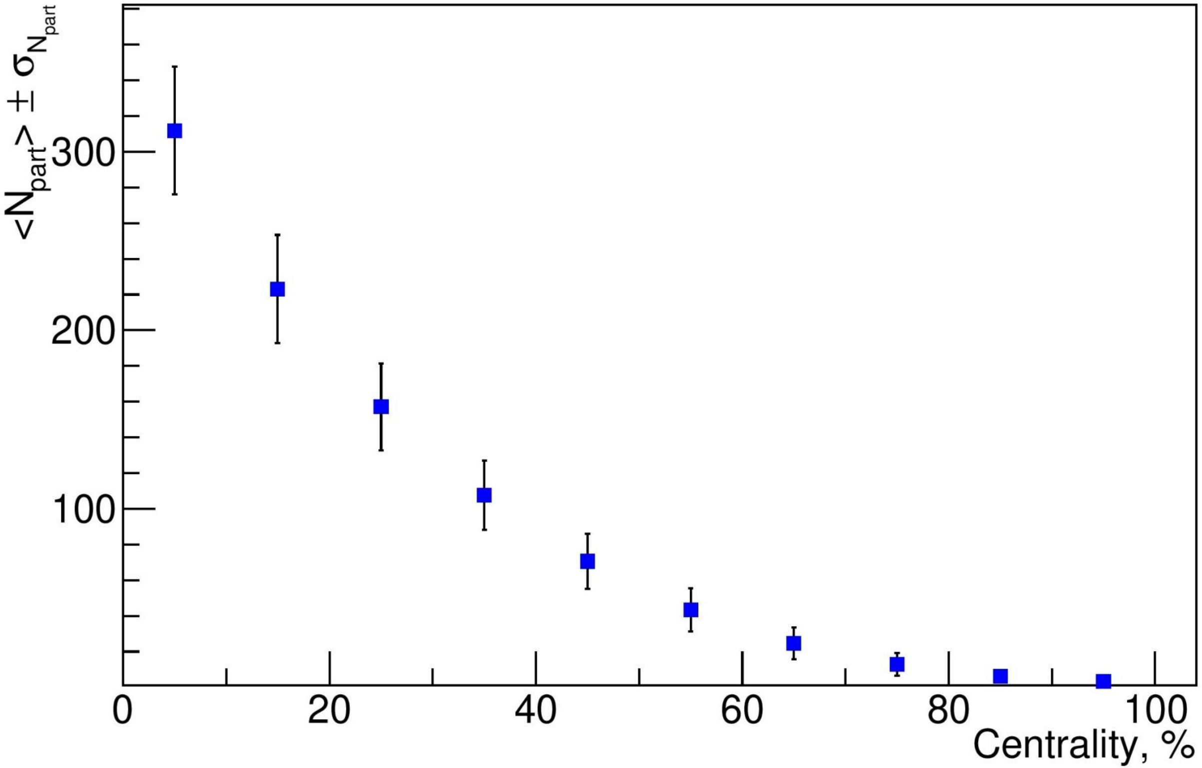
N_{part} distribution in centrality classes



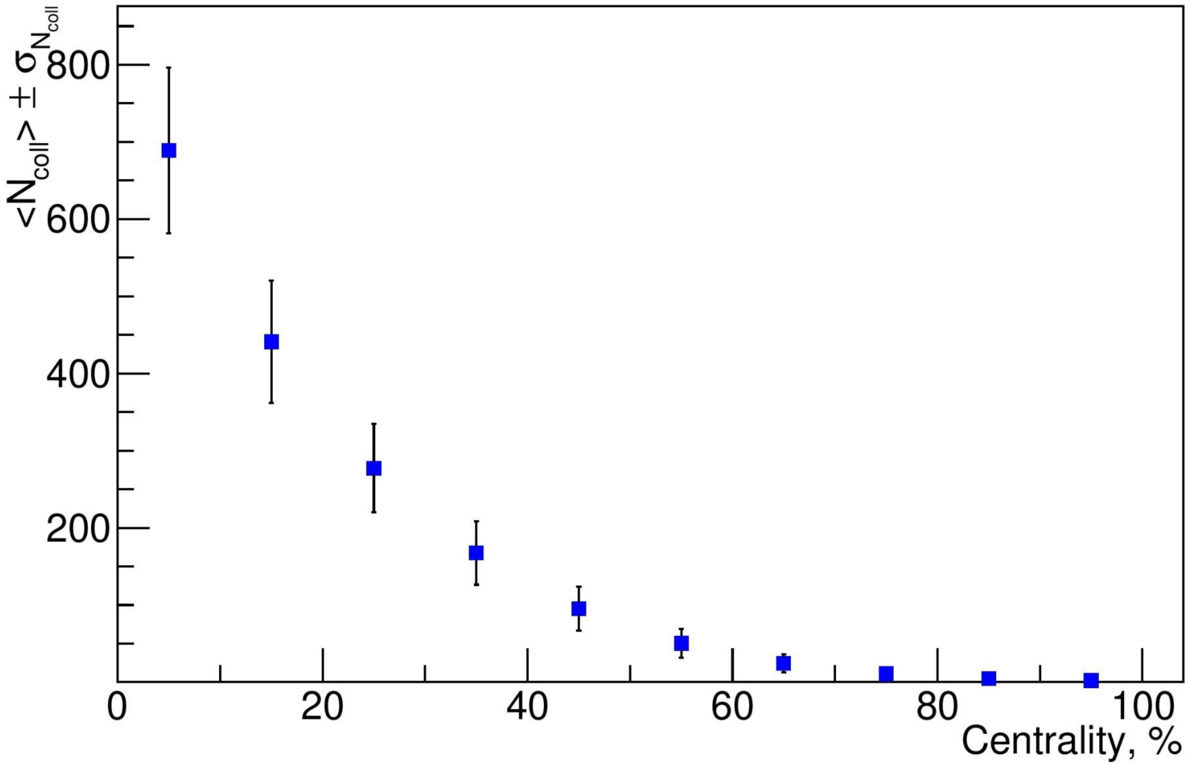
N_{coll} distribution in centrality classes



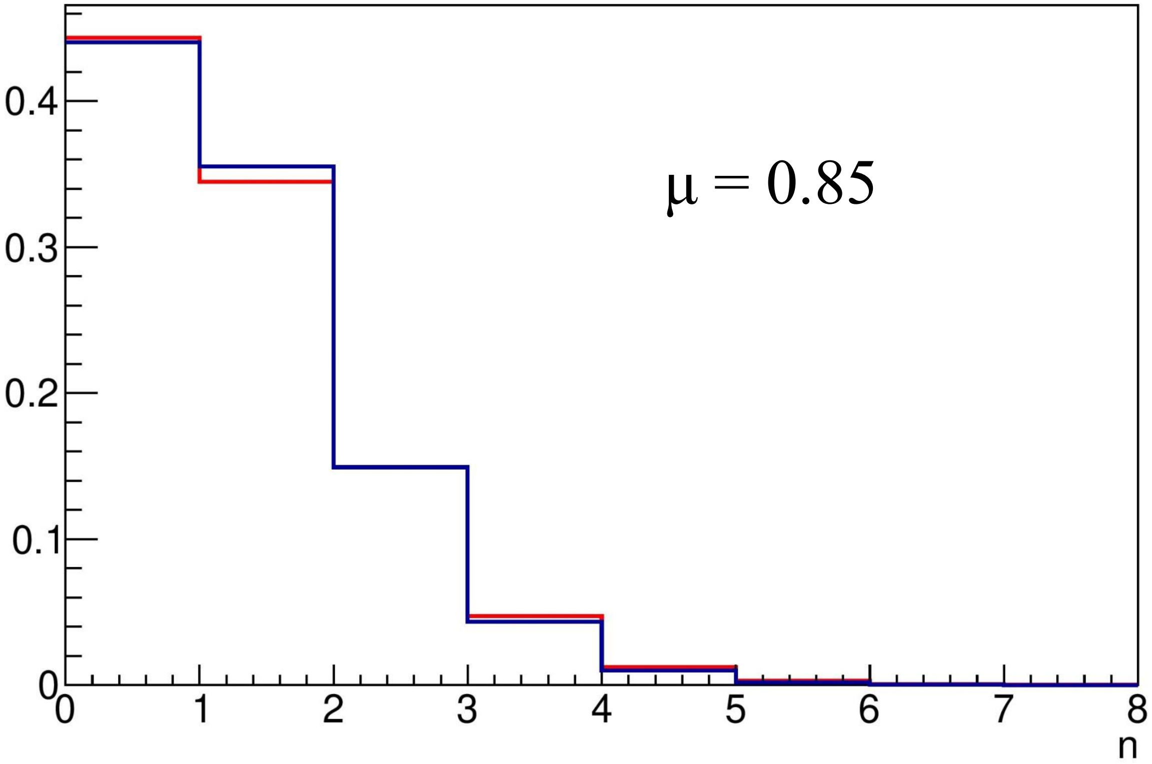
Average N_{part} parameter vs centrality



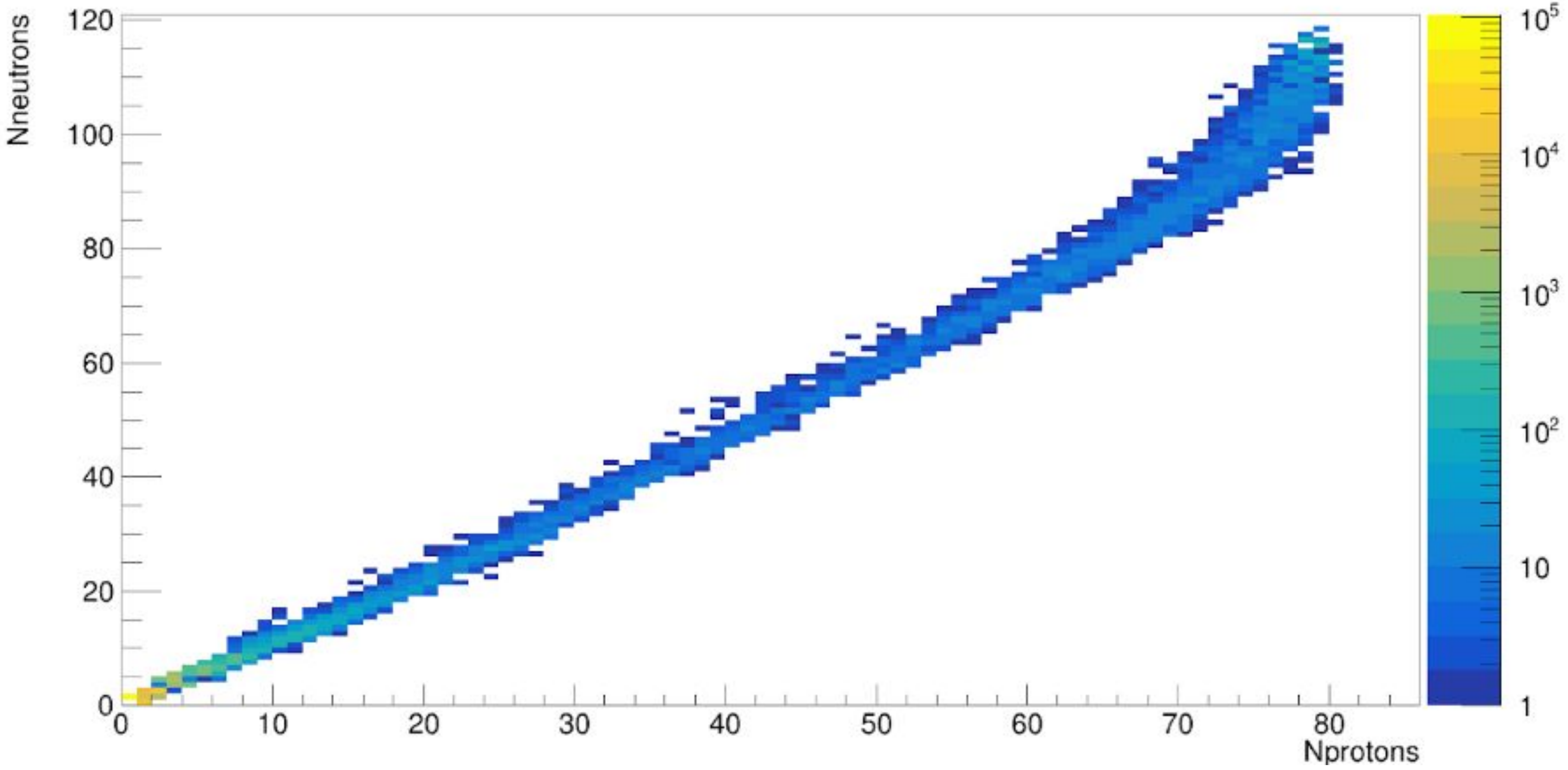
Average N_{coll} parameter vs centrality



NBD at different values of k

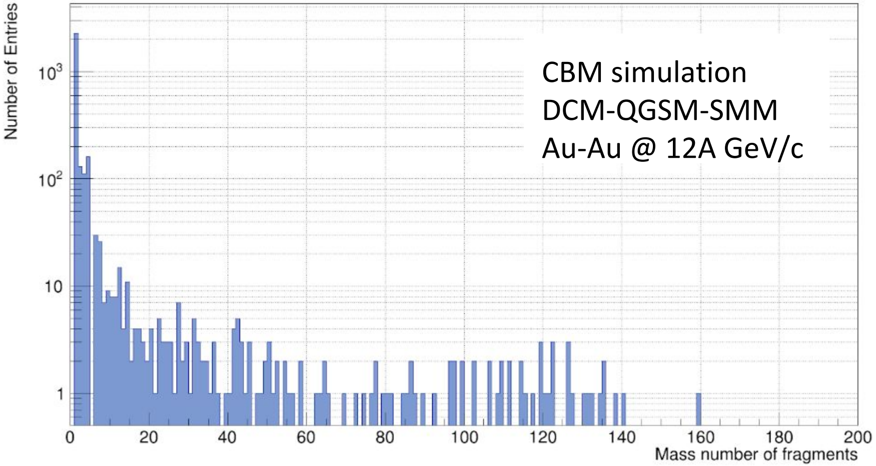


Number of protons and neutrons in fragment

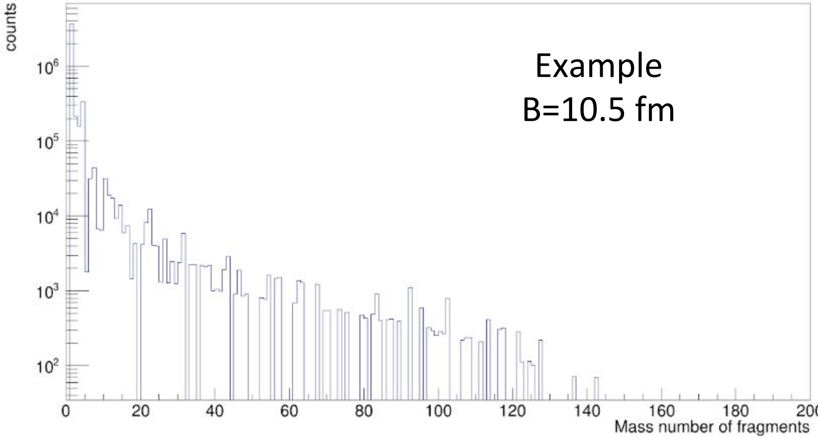


Mass number distribution of fragments for: check

Projection for a given impact parameter using N_{spec} from MC Glauber



Mass number distribution of fragments for big statistic



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Energy distributions of different fragments (shifted to beam energy)