Methods for centrality determination in heavy-ion collisions with the MPD experiment

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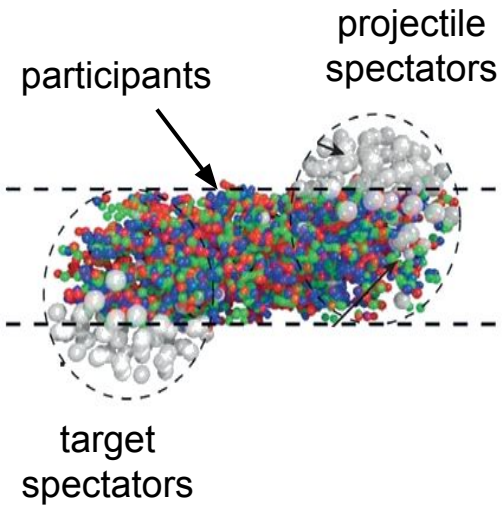
Motivation

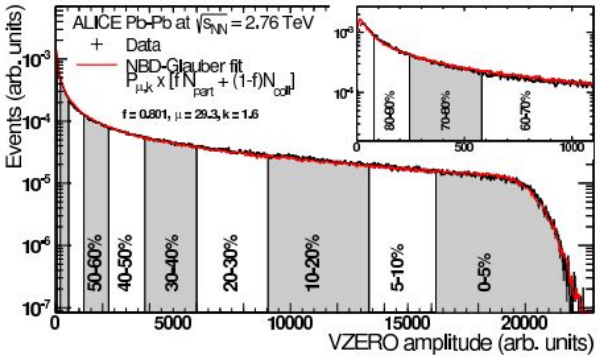
- Final state of the system produced in the heavy-ion collisions depends on its initial geometry
- Goal of centrality determination:
  map (on average) the collision geometry parameters
  to experimental observables (centrality estimators)
- Glauber model is commonly used to build such connection
- Centrality class: group of events corresponding to a given fraction (%) of the total cross section:

$$C_b = \frac{1}{\sigma_{inel}^{AA}} \int_0^b \frac{d\sigma}{db'} db'$$

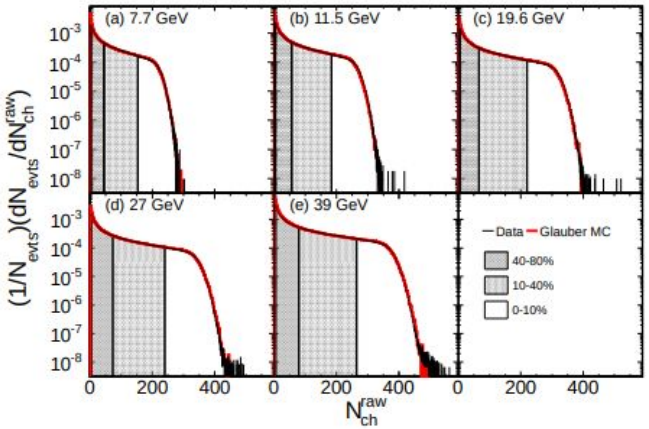


Why we need several centrality estimators

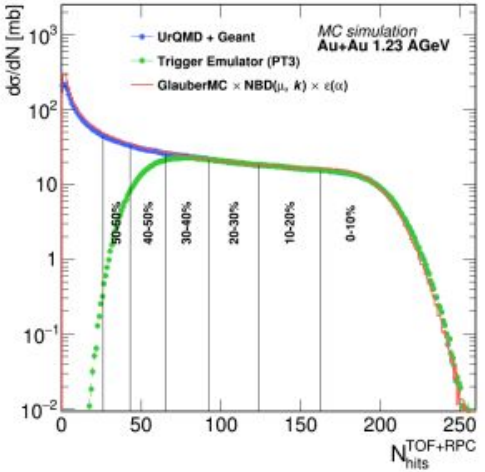
ALICE; Phys.Rev.C 88 (2013) 4, 044909



STAR; Phys.Rev.C 86 (2012) 054908



HADES; Eur.Phys.J.A 54 (2018) 5, 85

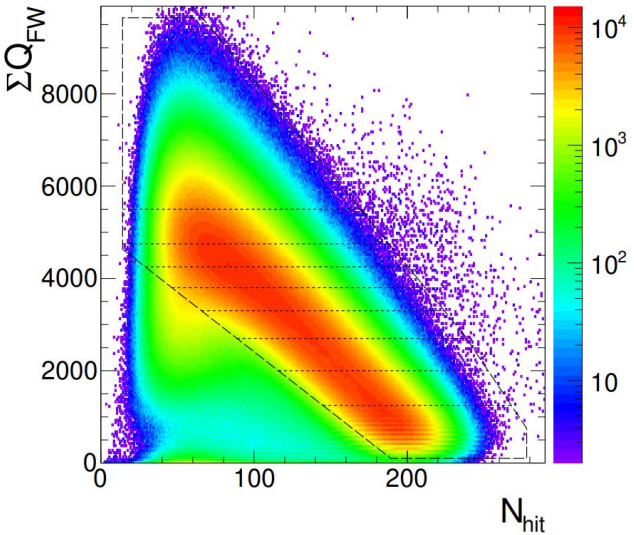


- MC-Glauber x NBD multiplicity fitting procedure is standard method for centrality determination
- MPD needs this method to compare data in the least experiment dependent way

Why we need several centrality estimators

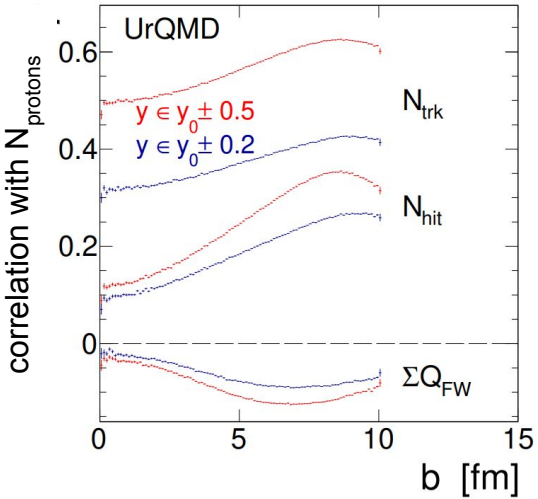
Anticorrelation between total charge of the spectator fragments (FW) and particle multiplicity

HADES; Phys.Rev.C 102 (2020) 2, 024914



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)

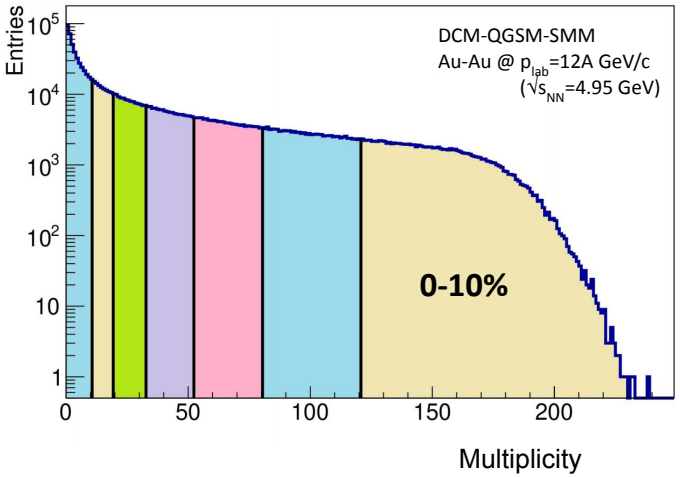
HADES; Phys.Rev.C 102 (2020) 2, 024914

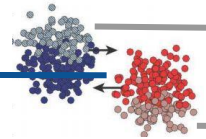


Avoid self-correlation biases when using spectators fragments for centrality estimation

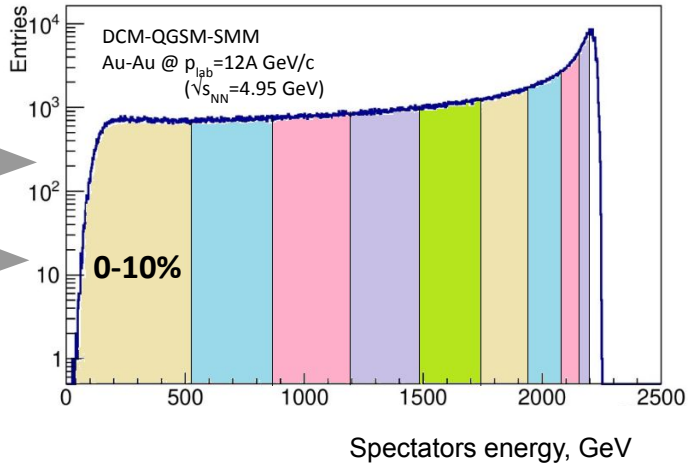
Centrality estimators in MPD

Produced charged particles





Projectile spectators



* these plots are illustrative only

MPD subsystems for centrality determination

Simulation setup

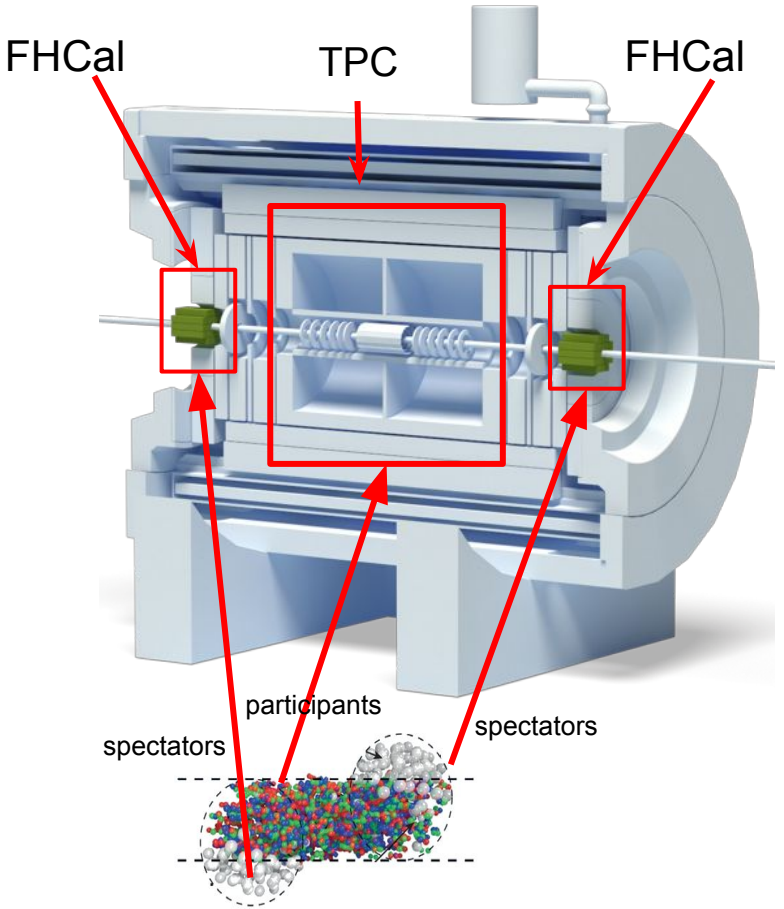
- DCM-QGSM-SMM

  M.Baznat et al. PPNL 17 (2020) 3, 303

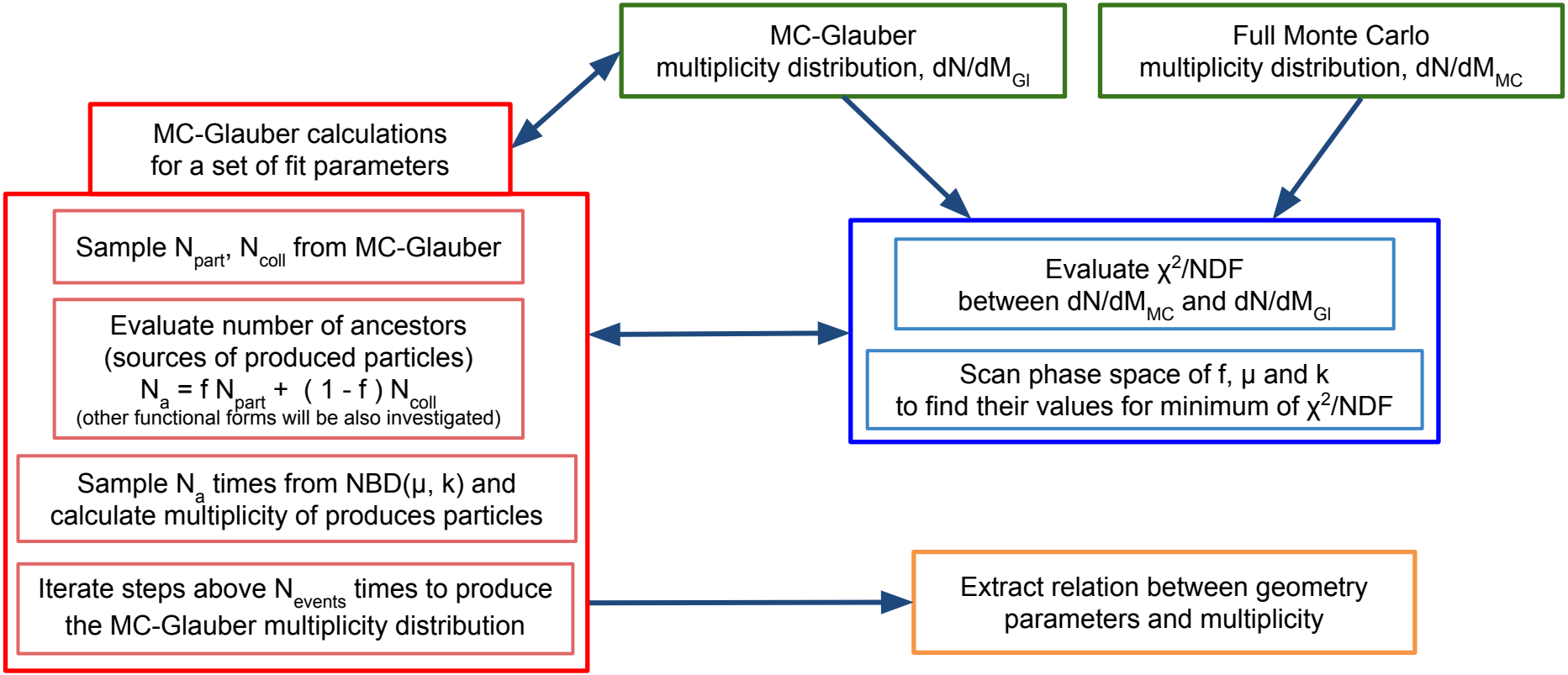
- Bi-Bi @ $\sqrt{s_{NN}}$ = 9.2 GeV
- Transport: GEANT4

Subsystems

- Multiplicity: TPC
- Spectators energy: FHCal

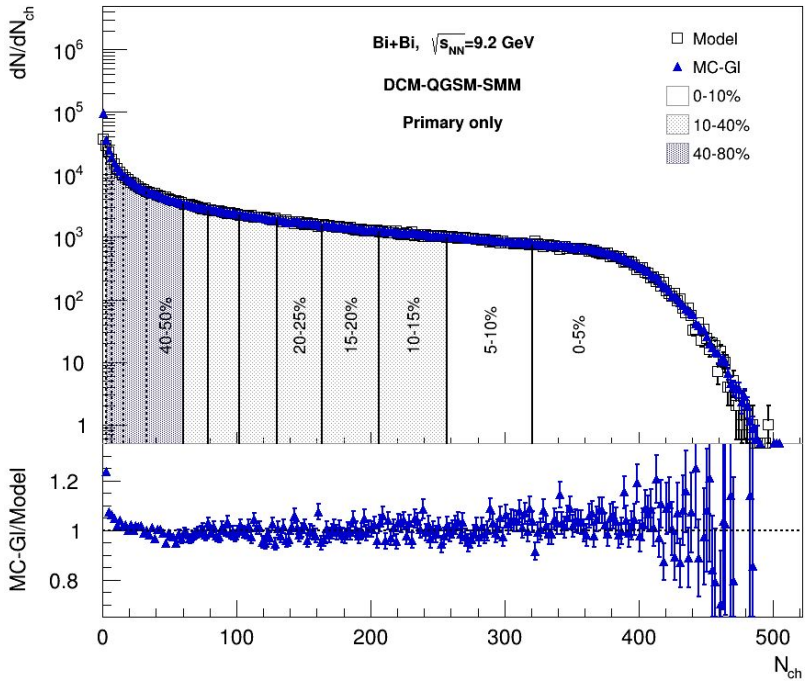


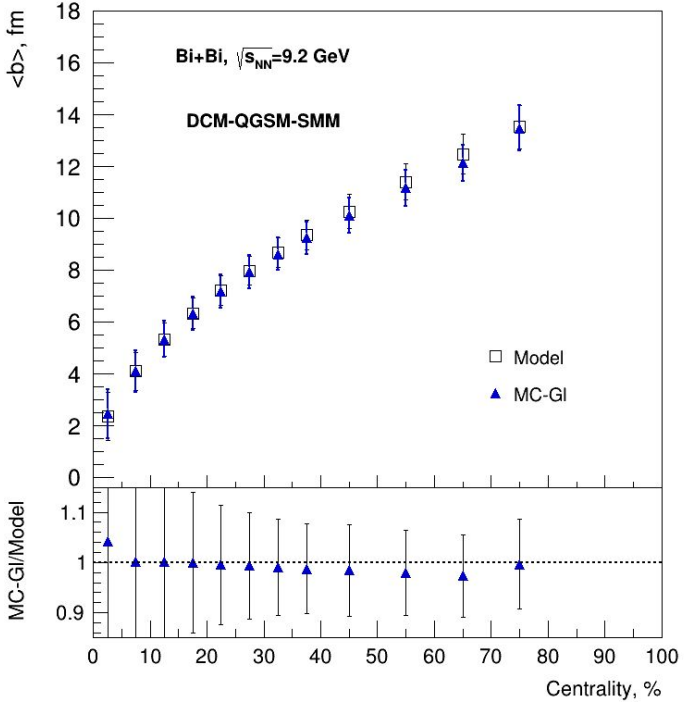
MC-Glauber + NBD fitting procedure



* For detailed description see talk about centrality in BM@N on Thursday (July 14th)

MC-Glauber fit result for Bi-Bi @ 9.2 GeV





χ^2/NDF=0.95±0.04;
f=0.07±0.19,
μ=0.3995±0.67,
k=10±11;
MinFitBin=15,
MaxFitBin=460

- Fit result is good
- Impact parameter distributions in different centrality classes reproduces ones from DCM-QGSM-SMM

MC-Glauber+Spectators fitting procedure

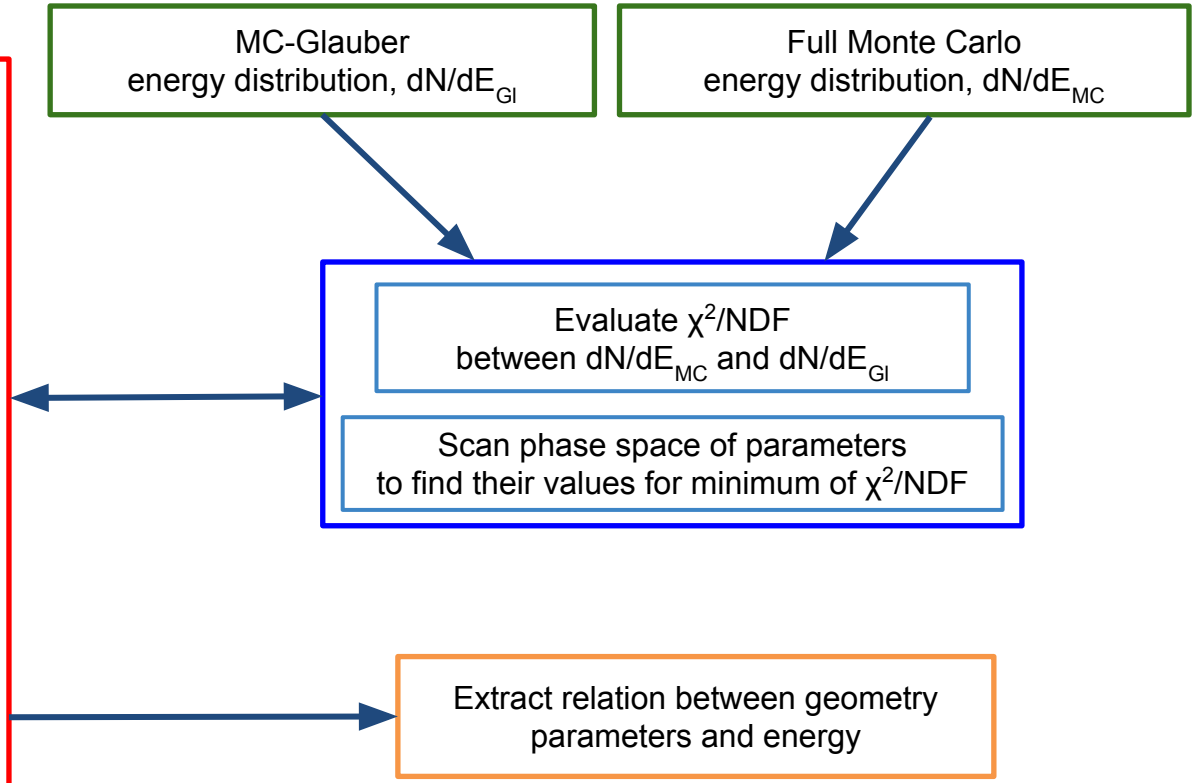
General idea

replace sampling of

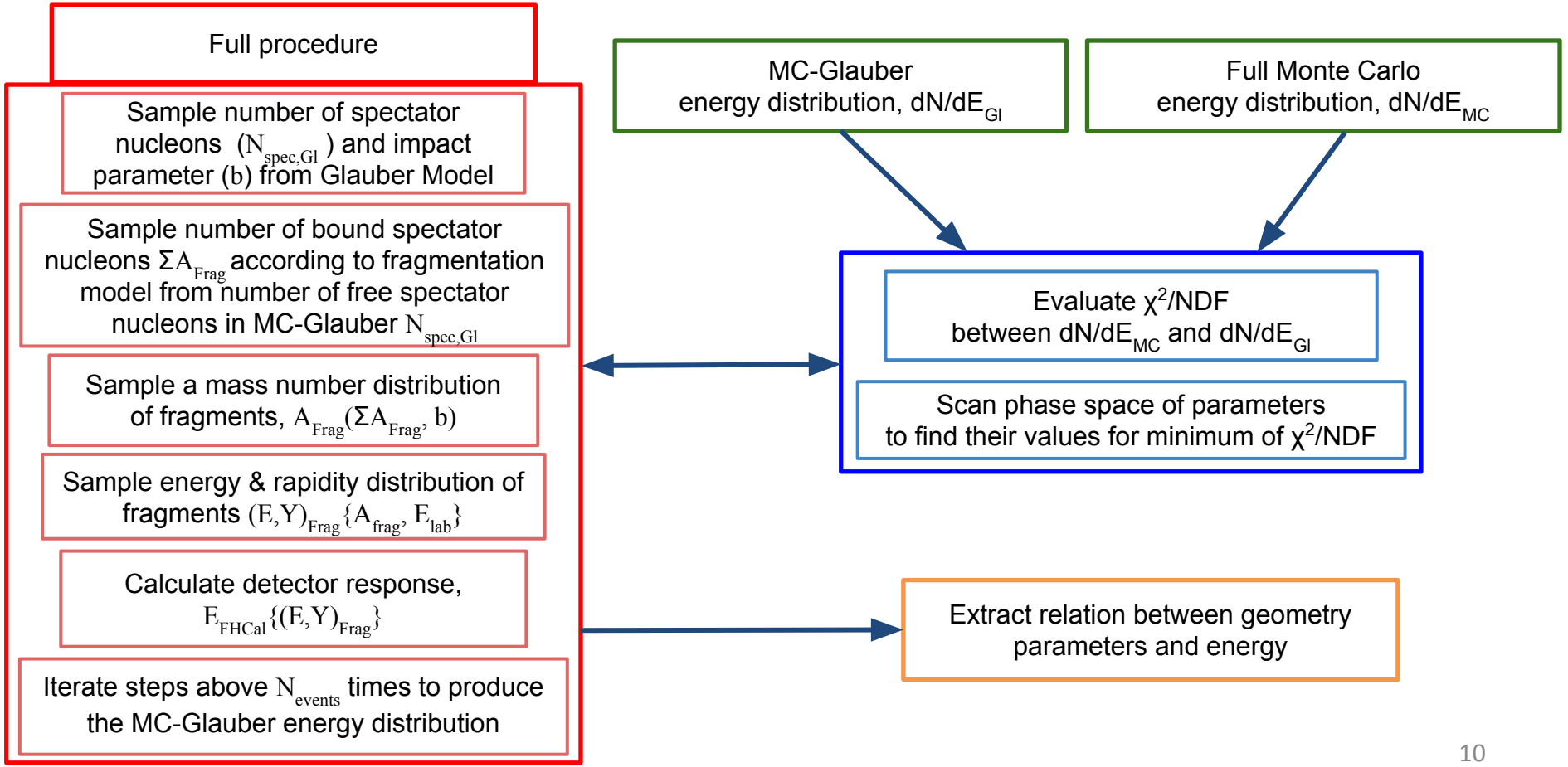
MC-Glauber **x** NBD multiplicity

with

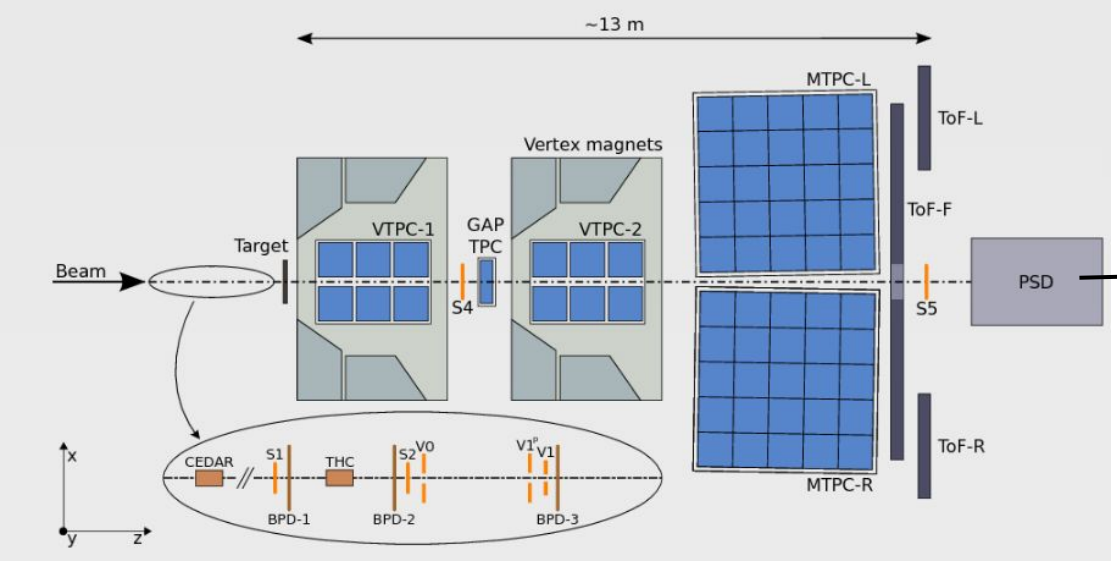
MC-Glauber **x** fragments energy

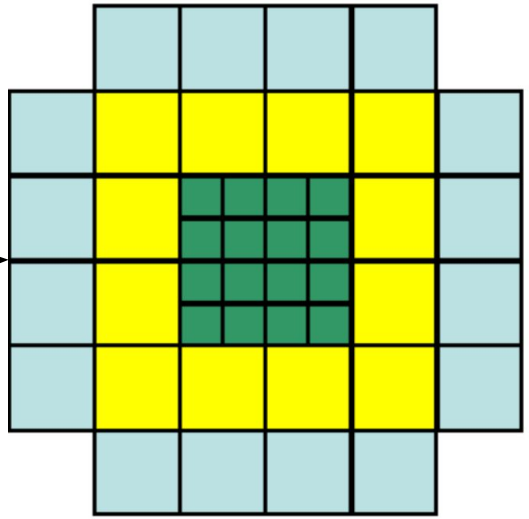


MC-Glauber+Spectators fitting procedure



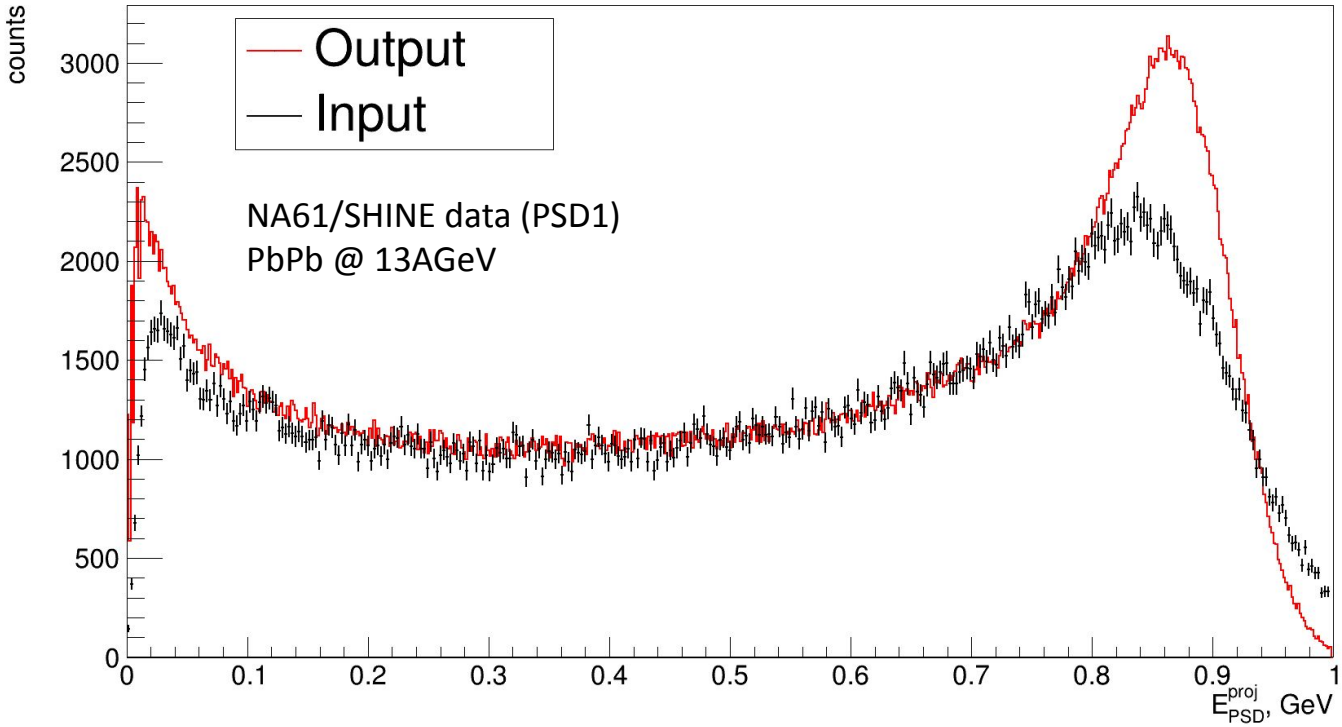
NA61/SHINE experimental setup

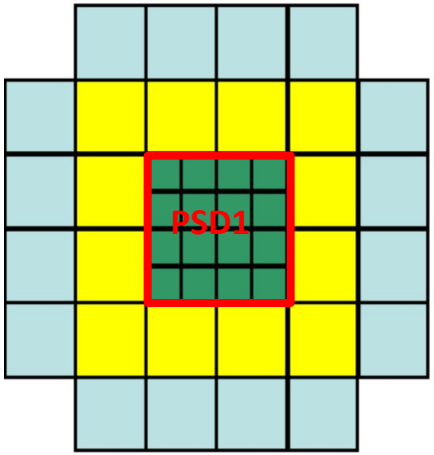




PSD detector layout

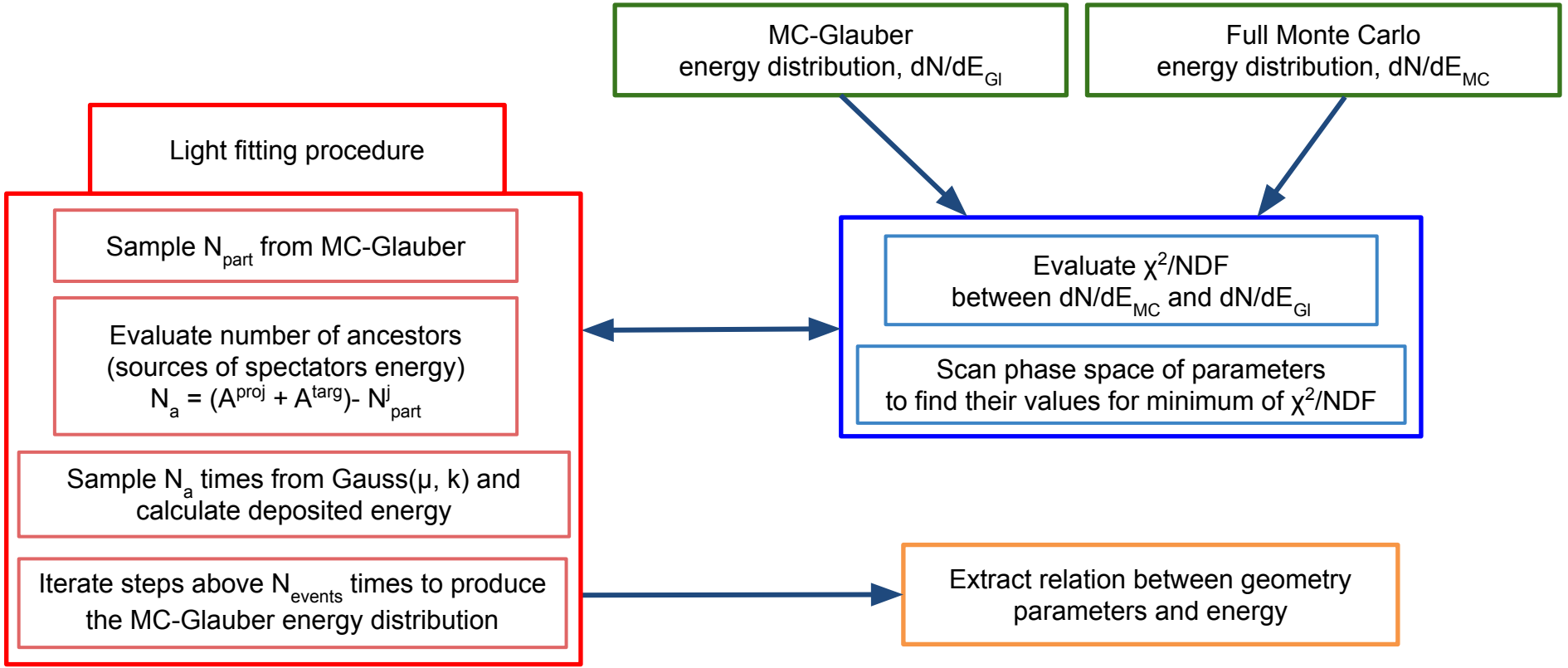
Full mode procedure (example for NA61)



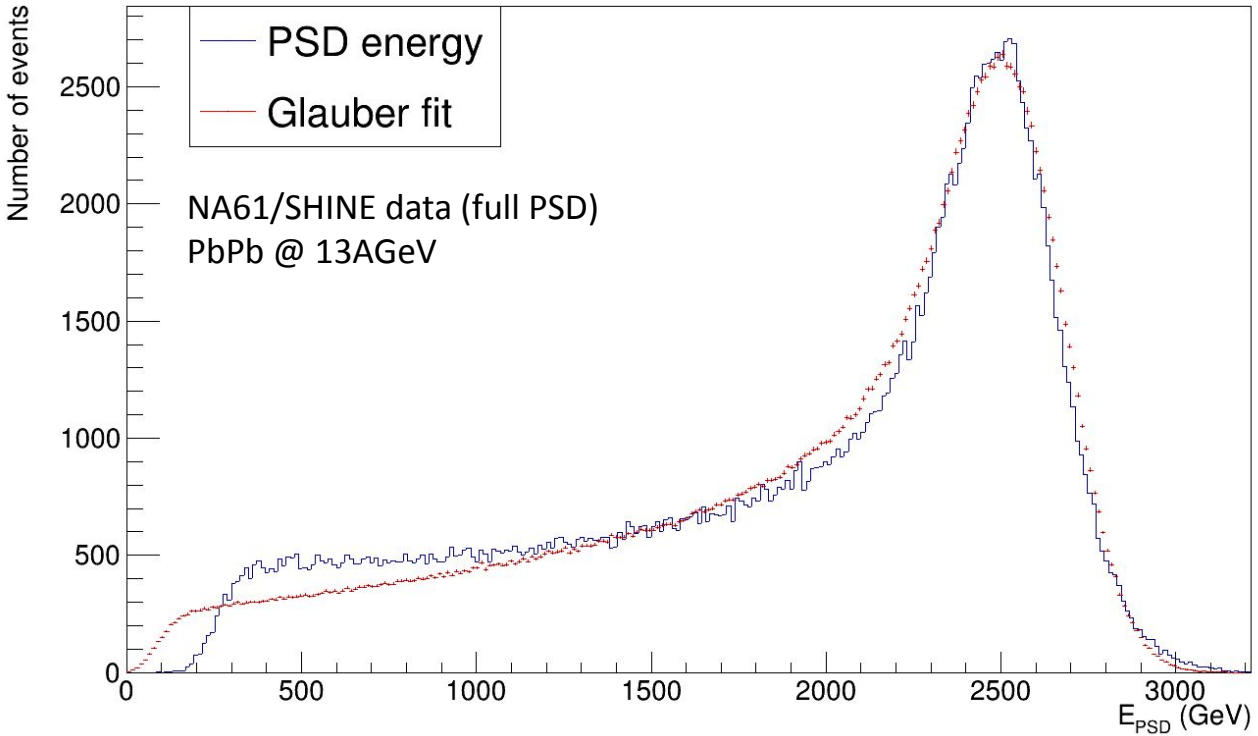


- Scaling along both X and Y axis is applied
- Form of energy distribution is reproducible

MC-Glauber+Spectators fitting procedure



Light mode procedure fit (example for NA61)



χ^2/NDF=18.1891±0.365028;
μ=12.4943,
k=8.9;
MinFitBin=17 (200 GeV),
MaxFitBin=250 (3000 GeV)

- Produced particles affect form of full PSD distribution
- Light mode maybe needs some additional parameters

Summary

- MC Glauber and multiplicity based fitting procedure is implemented for MPD
- Relation between impact parameter and centrality classes is extracted
- Software implementation of the procedure is ready and is supported by our group

- Centrality determination procedure based on spectators energy and MC Glauber model is proposed
- Results are tuned on the spectator production implemented in the DCM-QGSM-SMM model

Work in progress

- Investigate the effect on centrality determination due to the fragment loss in beam hole of the MPD FHCal
- Introduce parametrization for steps of centrality determination procedure based on spectators energy
- Apply this procedure for MPD FHCal simulations

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the Russian Academic Excellence Project (contract No. 02.a03.21.0005, 27.08.2013)

Backup

MC-Glauber model

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

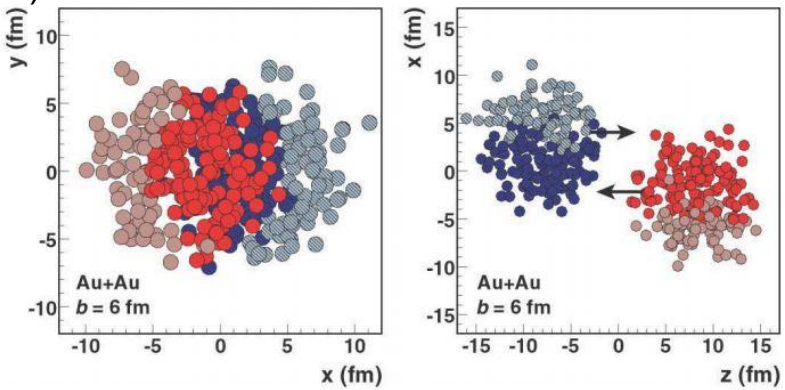
- Independent straight line trajectories of the nucleons
- A-A collision is treated as a sequence of independent binary NN collisions
- Monte-Carlo sampling of nucleons position for individual collisions

Main model parameters

- Colliding nuclei
  - 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: ARNPS57:205-243,2007



Geometry parameters

b – impact parameter

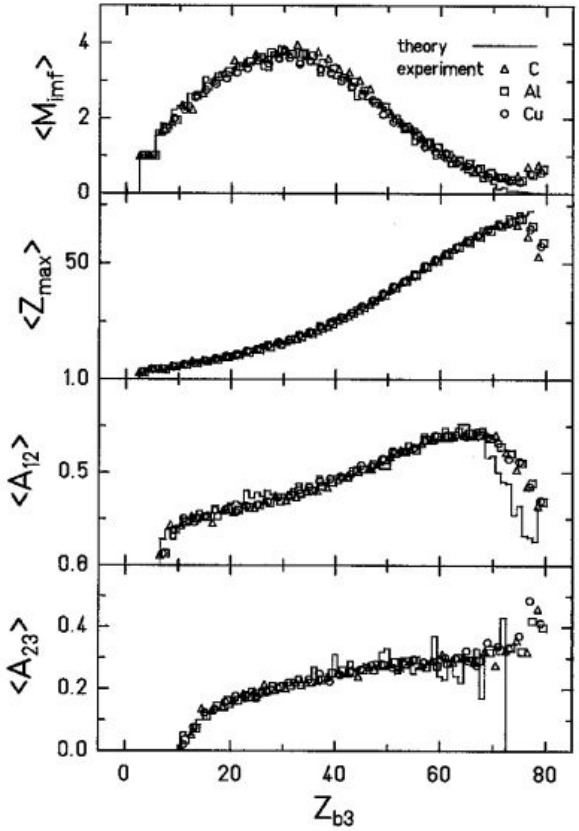
N_{part} – number of nucleons participating in the collision

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

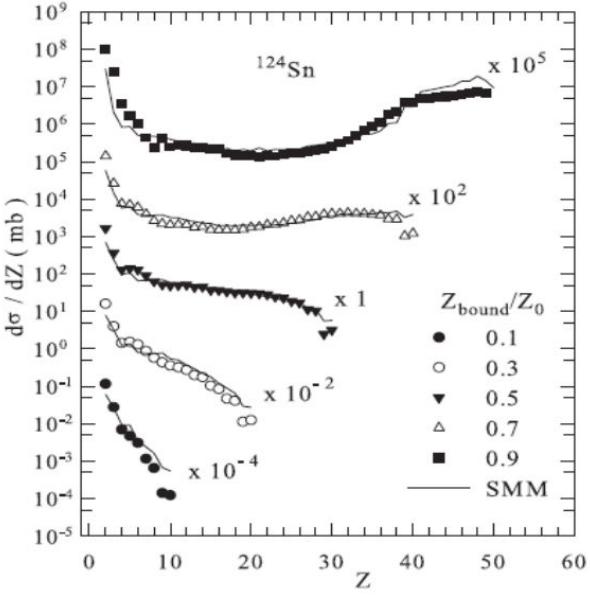
N_{coll} – number of binary NN collisions

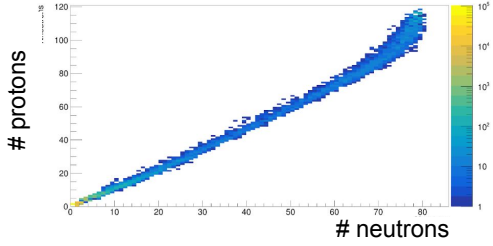
SMM description of the ALADIN's fragmentation data

A.S. Botvina et al. NPA 584 (1995) 737

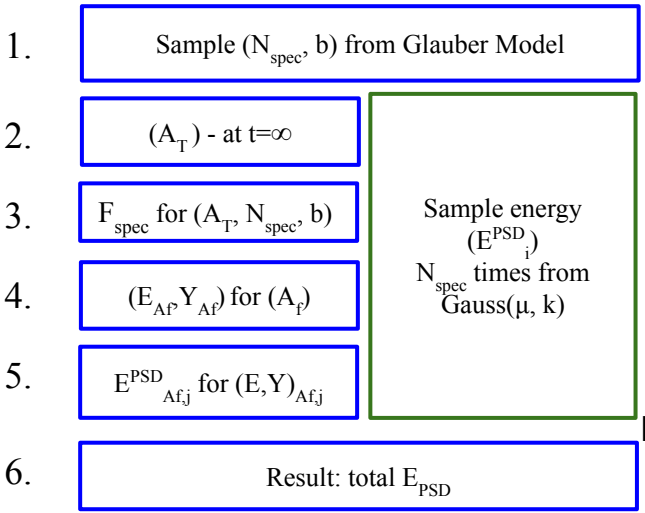


R.Ogul et al. PRC 83, 024608 (2011)





Mass number of fragments sampling for given event: new procedure



1. Fill set of 2D probability distribution of A_{frag} and N_A for each set of (A_{tot},N_{spec},b)
2. Reset all pairs $(A_{frag}, N_A)_i$, N_U=0
3. Generated pair $(A_{frag}, N_A)_i$,

   if:

   a. A_{frag} already among existing pairs from (1, N_U-1), then skip

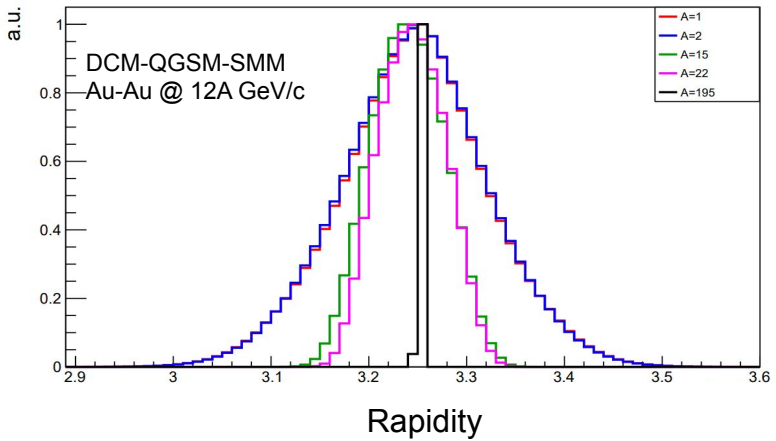
   b. $(\Sigma_{i=(1,NU)} N^i_A A^i_{frag}) > A_{tot}$ then go to step 2

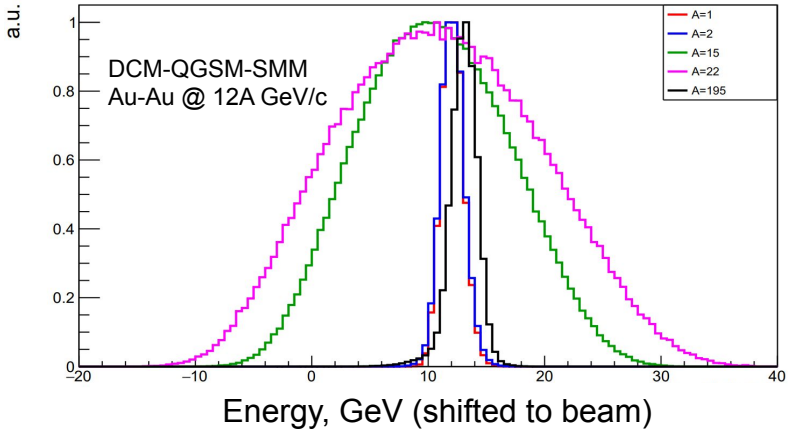
   else:

   Add $(A_{frag}, N_A)_i$ to the list of pairs, increment $N_U=N_U+1$

Result: a set of N_U pairs (A_{frag}, N_A) with $A_{tot} = N^1_A A^1_{frag} + N^2_A A^2_{frag} + \ldots N^{NU}_A A^{NU}_{frag}$

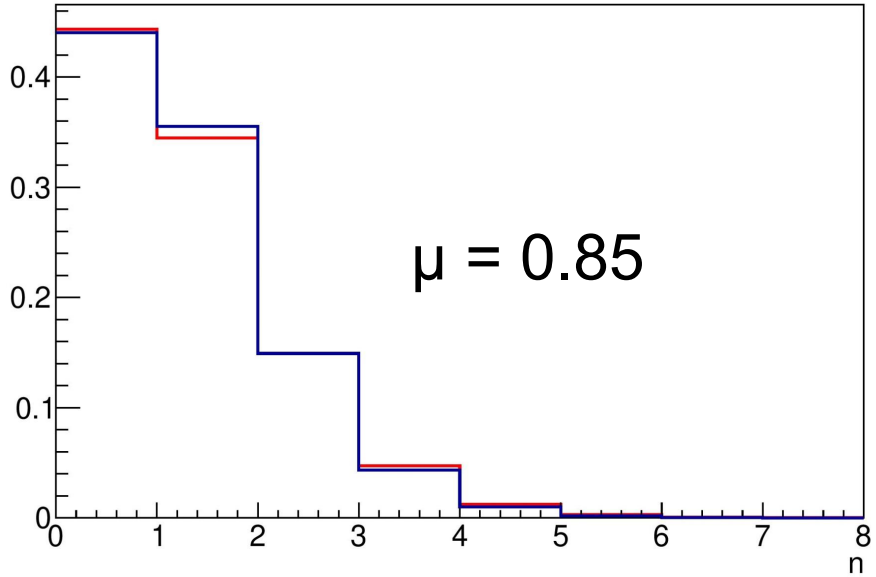
Population of fragments with energy and rapidity

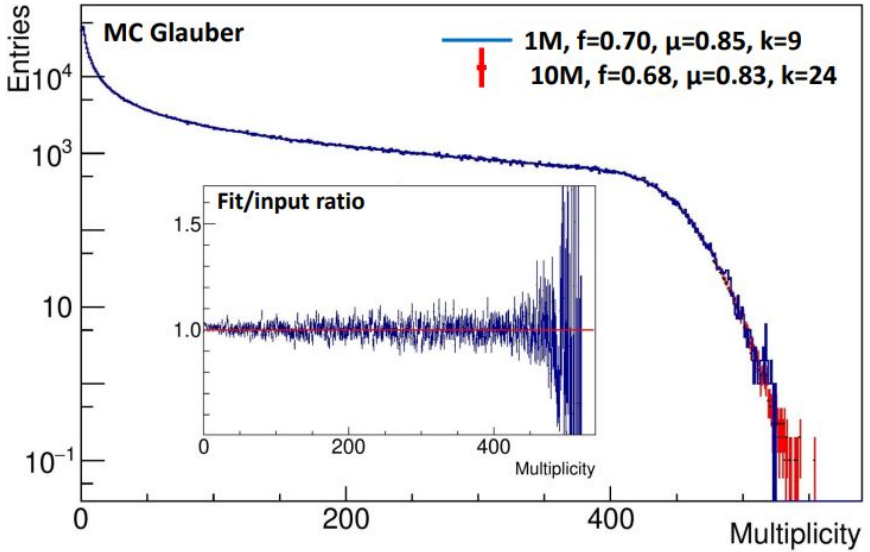




- Energy and rapidity distributions have different shapes for different fragment mass
- Shapes are used as input for sampling energy & rapidity values for each fragment

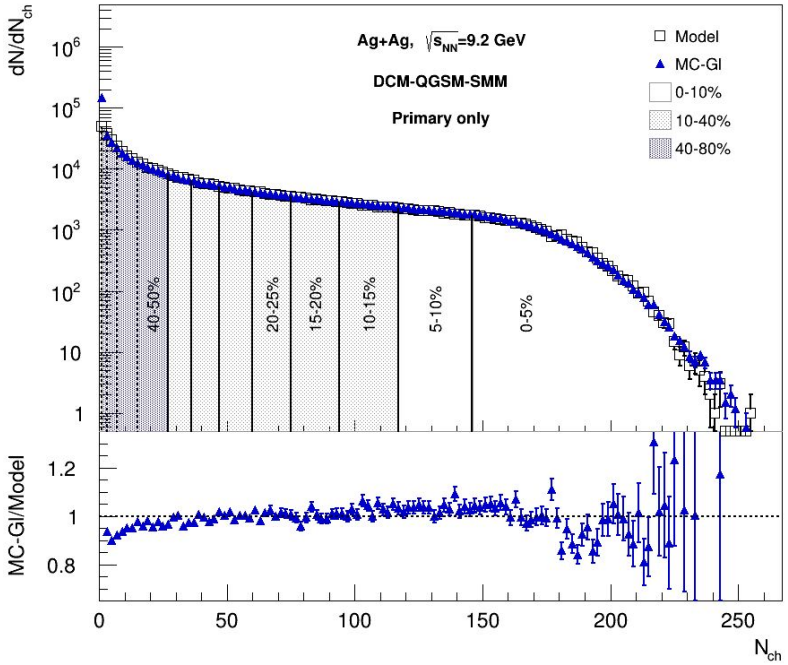
NBD at different values of k

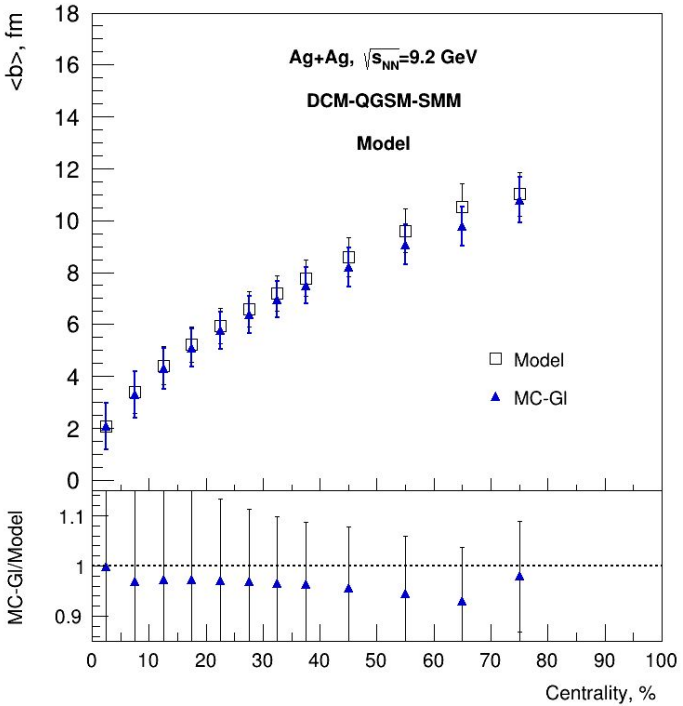




MC Glauber fit results are in
good agreement with simulated input

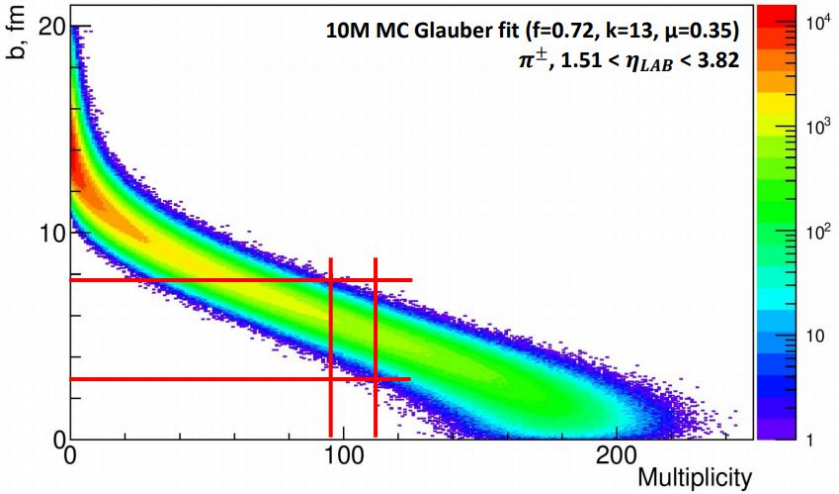
MC-Glauber fit result for AgAg @ 9.2 GeV

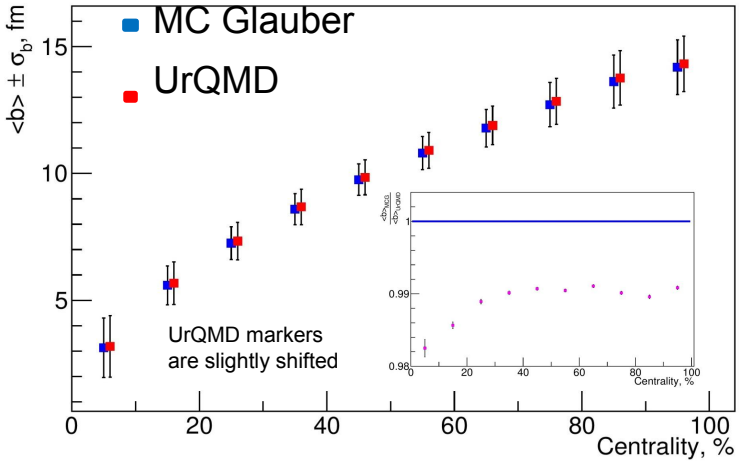




χ^2=1.56±0.07;
f=0.13±0.12,
μ=0.471±0.593,
k=1±0.02;
MinFitBin=20,
MaxFitBin=230

Centrality determination using STS multiplicity





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