Centrality determination in run8

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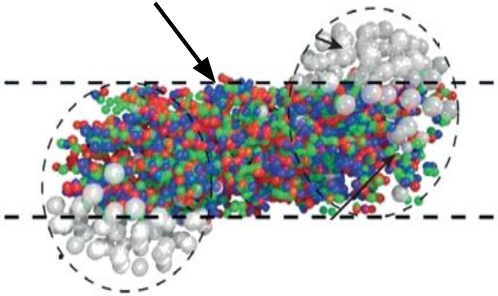
Motivation for centrality determination

- Evolution of matter produced in heavy-ion collisions depends on its initial geometry

- **Goal of centrality determination**:
  map (on average) the collision geometry parameters to experimental observables (centrality estimators)

- Centrality class S_1-S_2: group of events corresponding to a given fraction (in %) of the total cross section:

$$C_S = \frac{1}{\sigma_{inel}^{AA}} \int_{S_1}^{S_2} \frac{d\sigma}{dS} dS$$



BM@N subsystems for centrality determination

Data:

- run8 Xe-CsI @3.8*A* GeV
- CCT2
- vtxChi2/vtxNdf > 0.1
- 10000 < BC1Integral < 40000 (old cut)

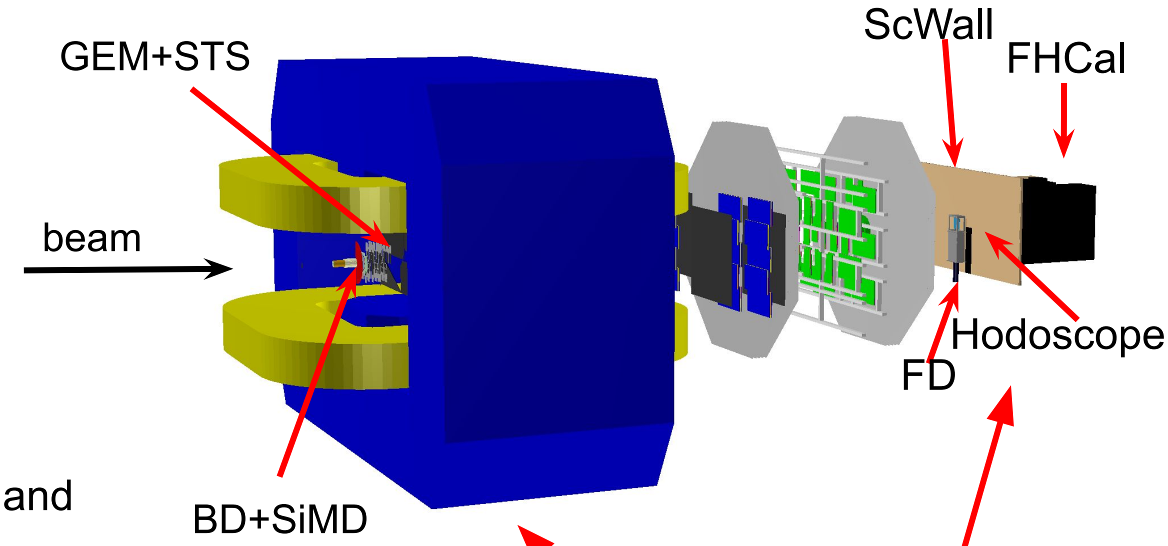
  or

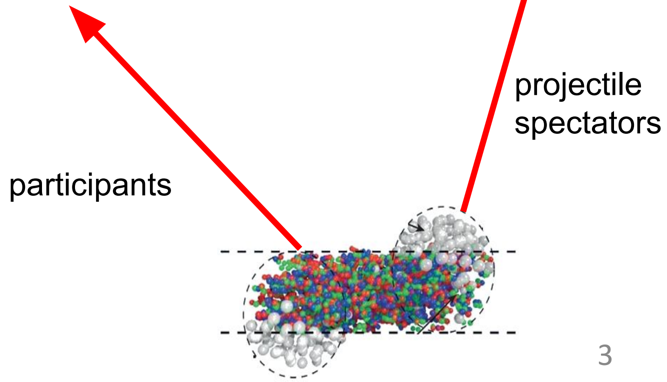
- BC1Integral VS FDIntegral cut and

  Graphic cut for N_{tracks} and STS digits (new cuts)

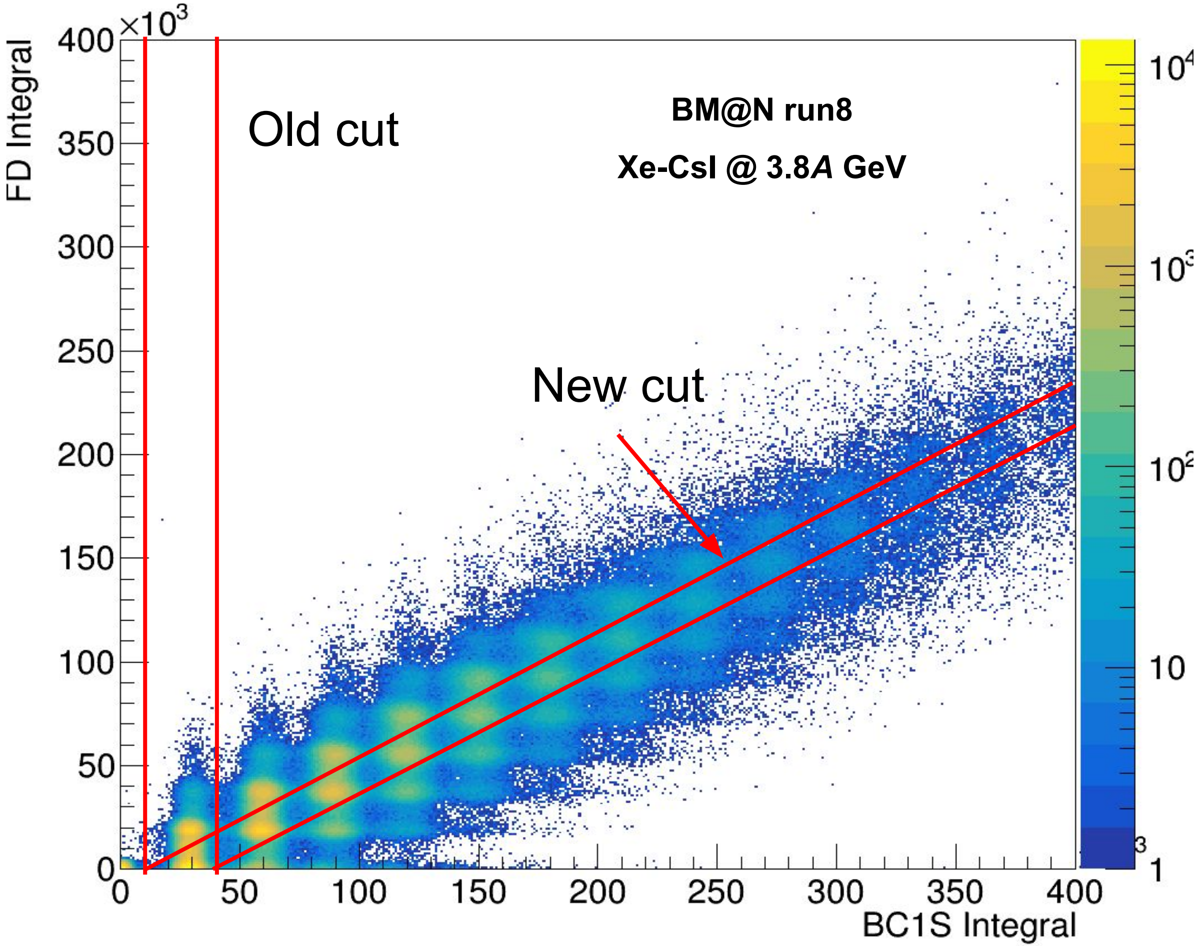
Subsystems

- Participants: **Tracking system GEM+STS**, BD, SiMD
- Spectators: FHCal, Hodoscope, ScWall, FD





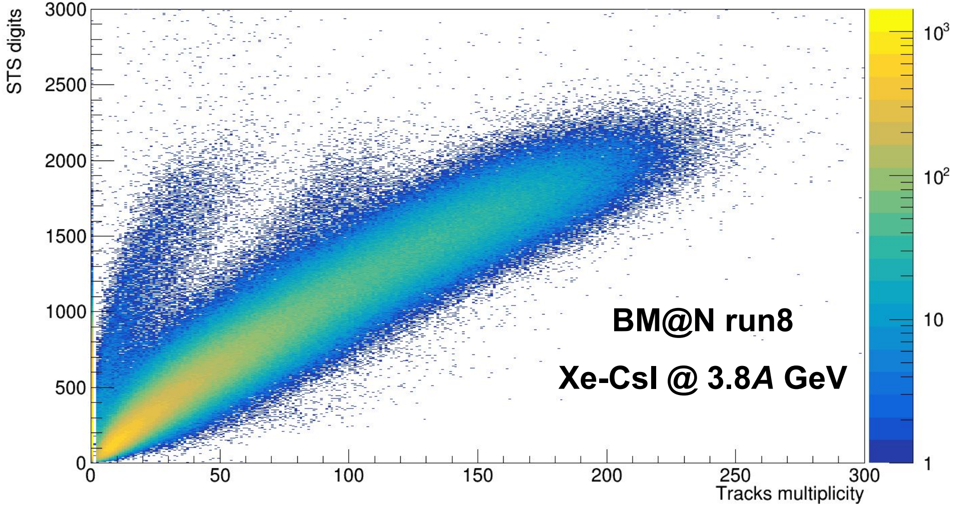
BC1 Integral cut improvement



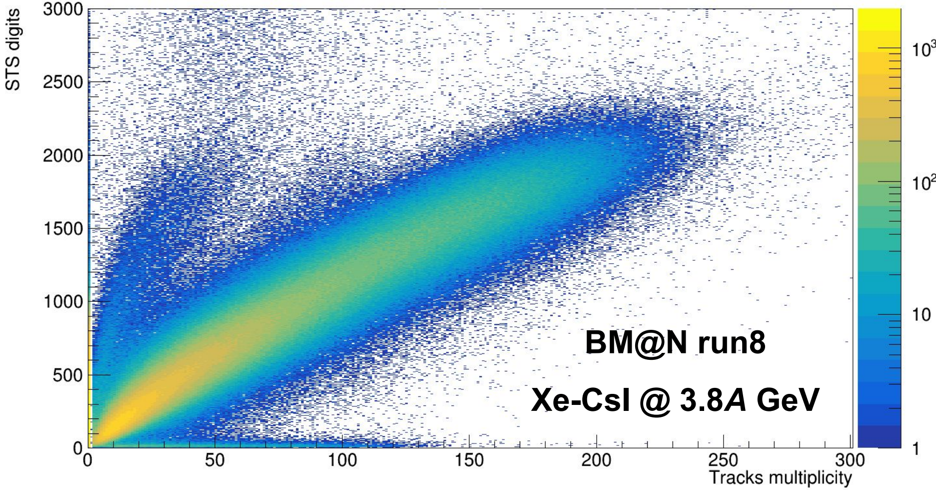
- Suggestions by S.Sedykh:
- New cut saves all events where only one collision occurs
- Difference: 23% ⟶ 43% of all events

Additional graphic cut

BC1 old cut



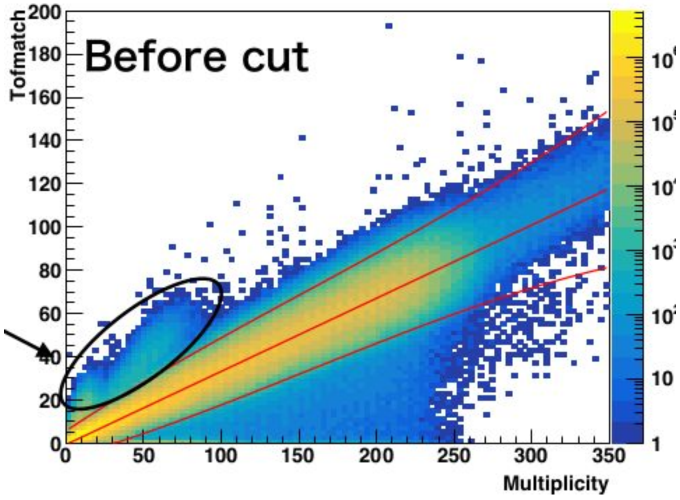
BC1 new cut

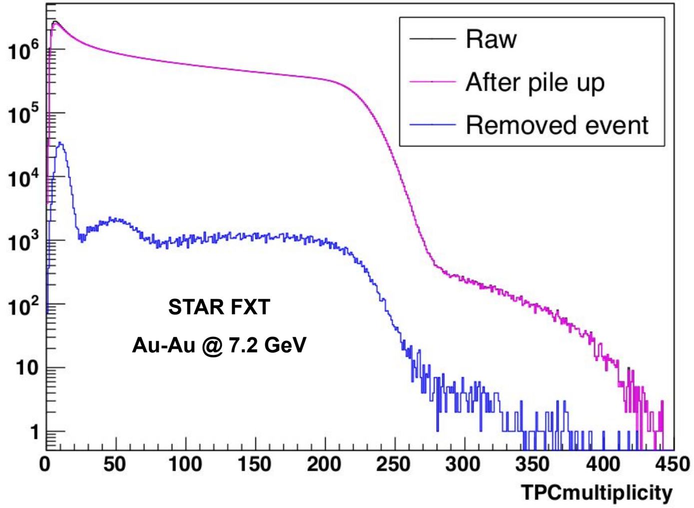


- There are some additional structures of events with unusual behaviour which may affect physical results

- Those events can be declined using graphic cut

Additional graphic cut



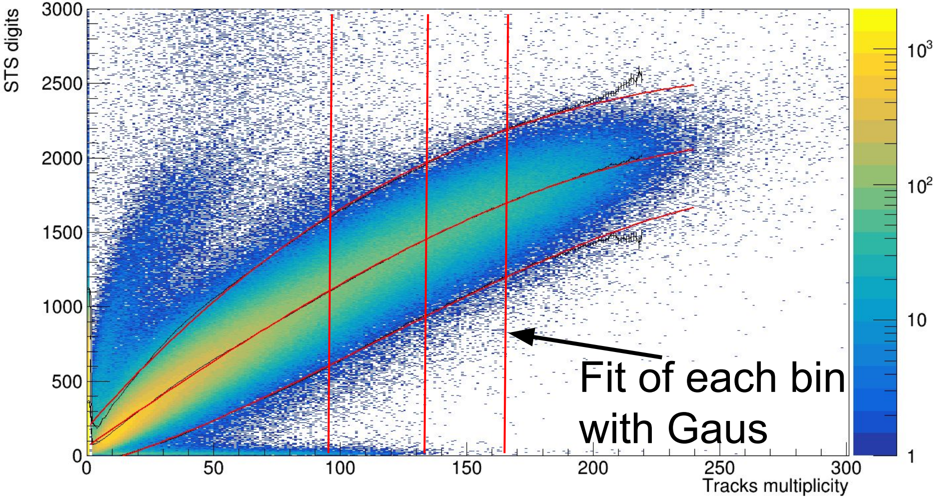


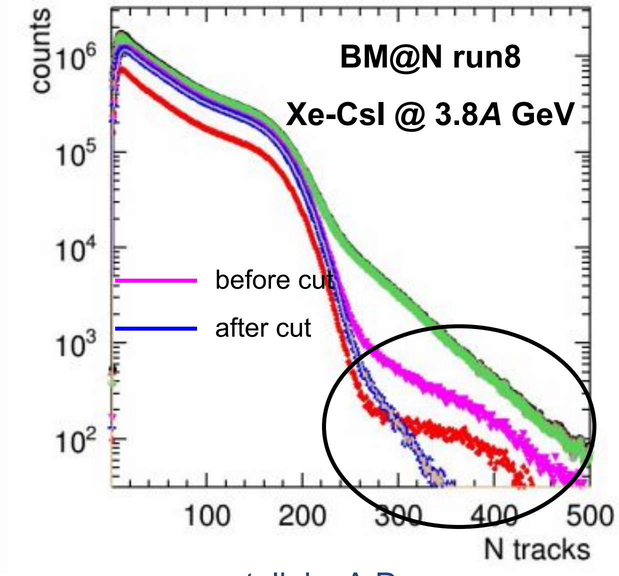
results from STAR by K.Okubo

- In the STAR's case number of tracks matched with TOF were used to reject events with unusual behaviour

Additional graphic cut

BC1 new cut





see talk by A.Demanov

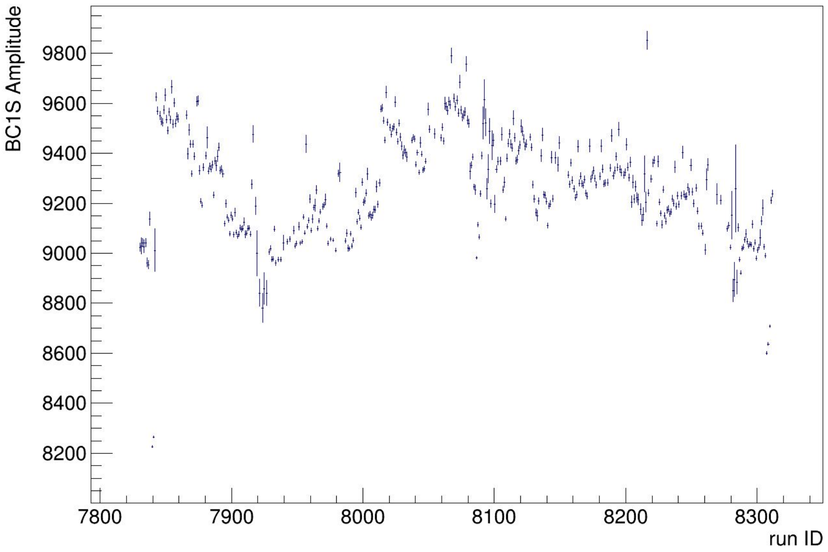
- Graphic cut was performed to throw out all events with unusual behaviour:

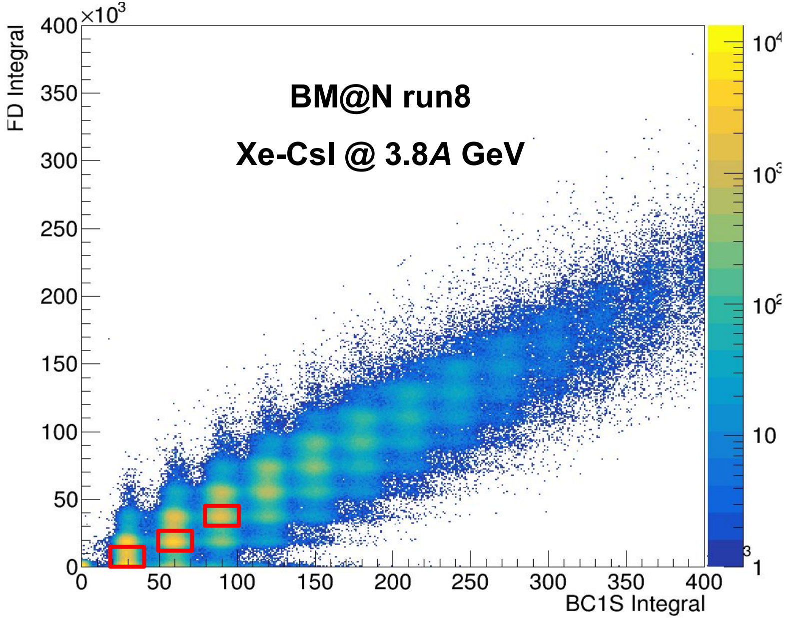
  $STS_{max}(N_{tracks})$=4.6e-05*N^3-0.052*N^2+19.4*N+188 (mean+3σ)

  $STS_{min}(N_{tracks})$=-9.6e-05*N^3+0.033*N^2+4.8*N-74 (mean-3σ)

- Difference: 23% $\longrightarrow$ 41% of all events

Future improvements





- Calibrate BC1 Amplitude over all runs to improve FD vs BC1 Integrals correlation
- Use areas of each peak instead of line on this correlation

- Finally, we should adjust before/after protection window for physics analysis

Centrality determination based on Monte-Carlo sampling of produced particles

For **multiplicity of produced particles** used in HADES, CBM, NA61/SHINE

Get (N_{part}, N_{coll}) from MC-Glauber

Calculate $N_a = fN_{part} + (1-f)N_{coll}$

Sample multiplicity of produced particles (S_i) N_a times from NBD (μ, k)

Result: total S_{tot}

MC-Glauber distribution

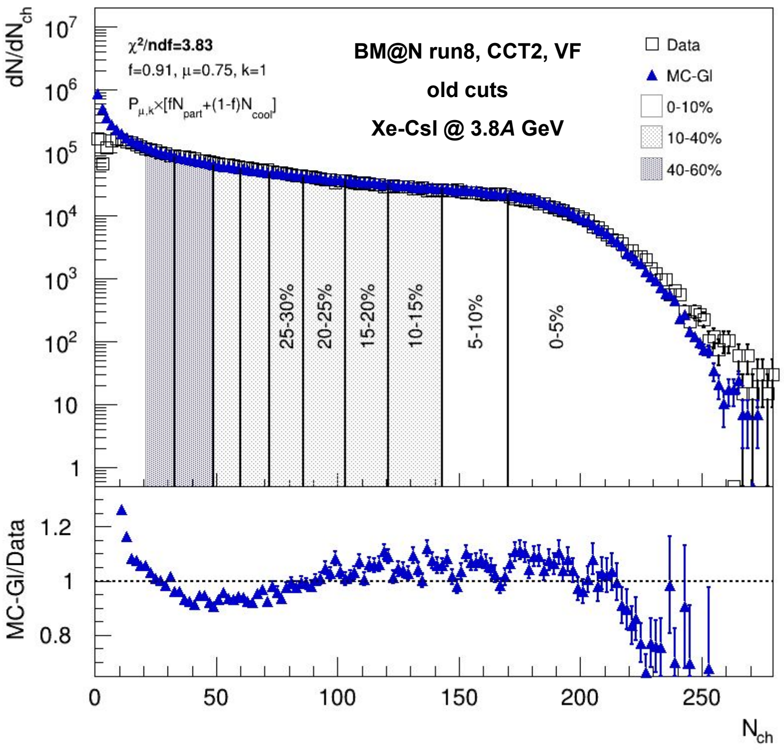
Full Monte-Carlo (real data) distribution

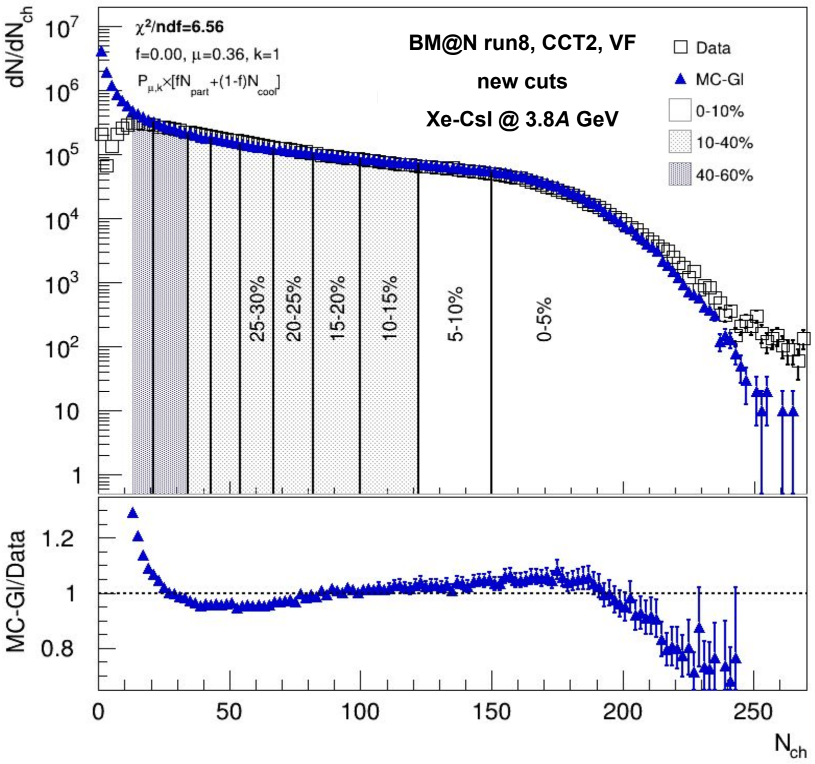
Evaluate χ^2 between $dN/dE_{MC/data}$ and dN/dE_{Gl}

Scan phase space of parameters to find their values for minimum of χ^2

Extract relation between geometry parameters and centrality estimator

Comparison with older results (E_{kin}=3.8 GeV)





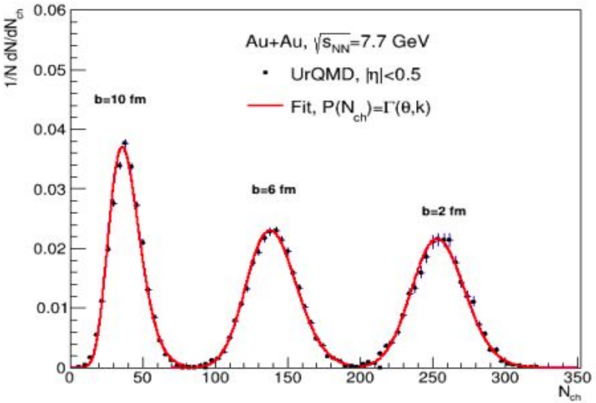
- Glauber fit improved in comparison with previous results
- CCT2 has good efficiency up to 60% centrality
- New centrality classes is used in analysis (see talk by M.Mamaev)

The Bayesian inversion method (Γ-fit): main assumptions

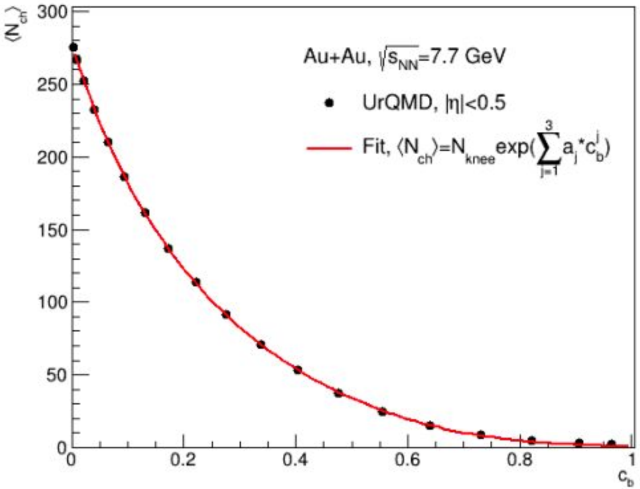
- Relation between multiplicity N_{ch} and impact parameter b is defined by the fluctuation kernel:

$$P(N_{ch}|c_b) = \frac{1}{\Gamma(k(c_b))\theta^k} N_{ch}^{k(c_b)-1} e^{-n/\theta}$$

$$c_b = \int_0^b P(b')db' \simeq \frac{\pi b^2}{\sigma_{inel}}$$ – centrality based on impact parameter



The results of fitting the multiplicity distribution for a fixed impact parameter



The dependence of the average value of multiplicity on centrality and the results of its fit

$$\frac{\sigma^2}{\langle N_{ch}\rangle} = \theta \simeq const$$

$$\langle N_{ch}\rangle = N_{knee}\exp\left(\sum_{j=1}^{3} a_j c_b^j\right), \quad k = \frac{\langle N_{ch}\rangle}{\theta}$$

Five fit parameters N_{knee}, θ, a_j

Reconstruction of b

- Normalized multiplicity distribution $P(N_{ch})$

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

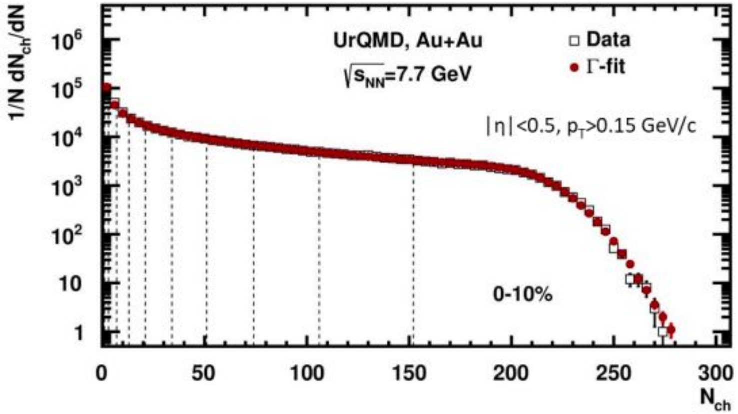
- Find probability of *b* for fixed range of N_{ch} using Bayes' theorem:

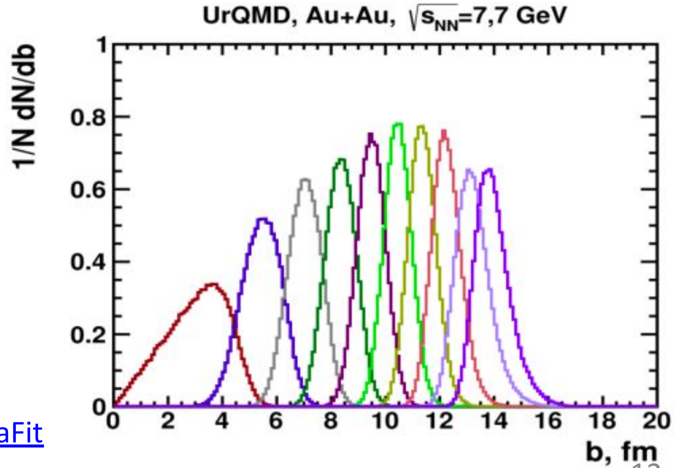
$$P(b|n_1 < N_{ch} < n_2) = P(b)\frac{\int_{n_1}^{n_2} P\,(b|N_{ch})dN_{ch}}{\int_{n_1}^{n_2} P\,(N_{ch})dN_{ch}}$$

- **The Bayesian inversion method consists of 2 steps:**

–Fit normalized multiplicity distribution with $P(N_{ch})$

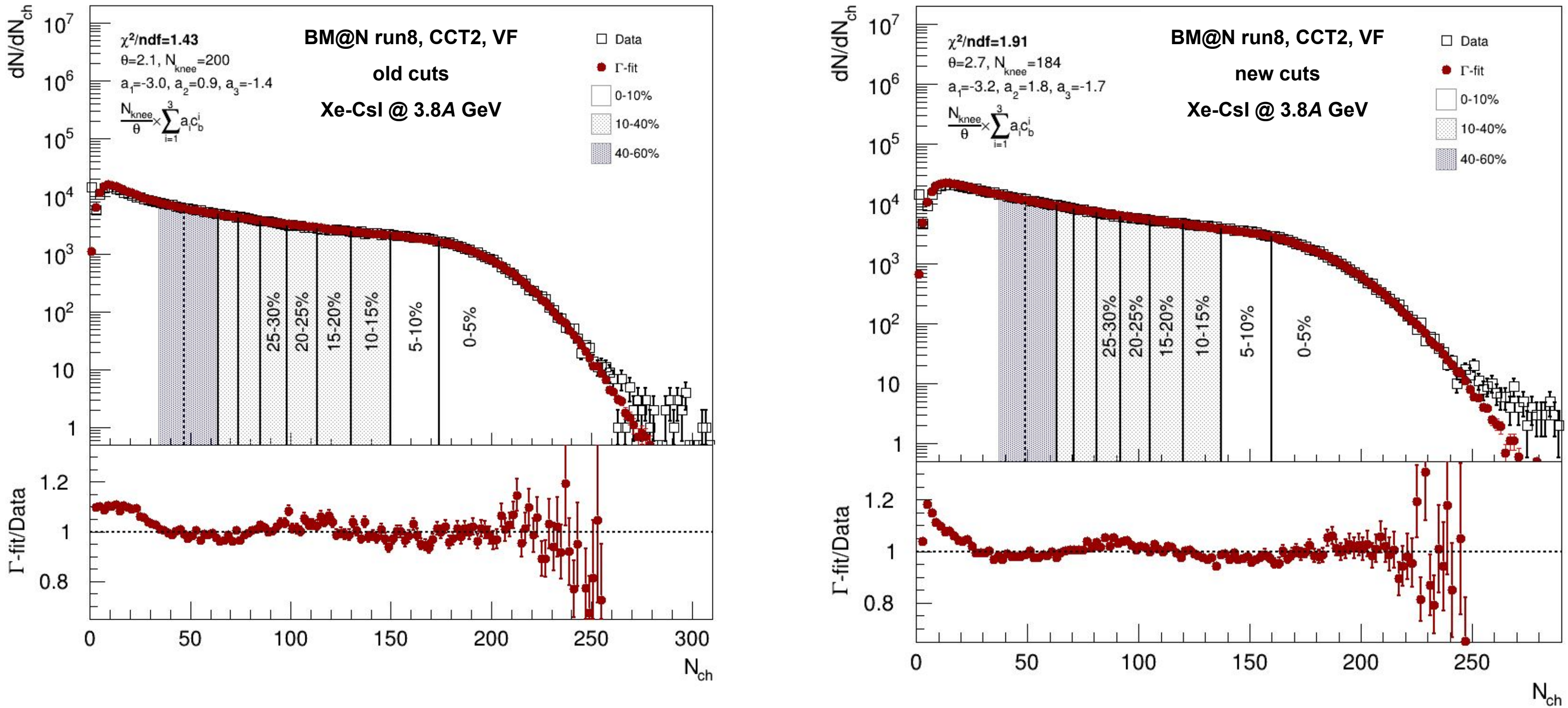
–Construct $P(b|N_{ch})$ using Bayes' theorem with parameters from the fit





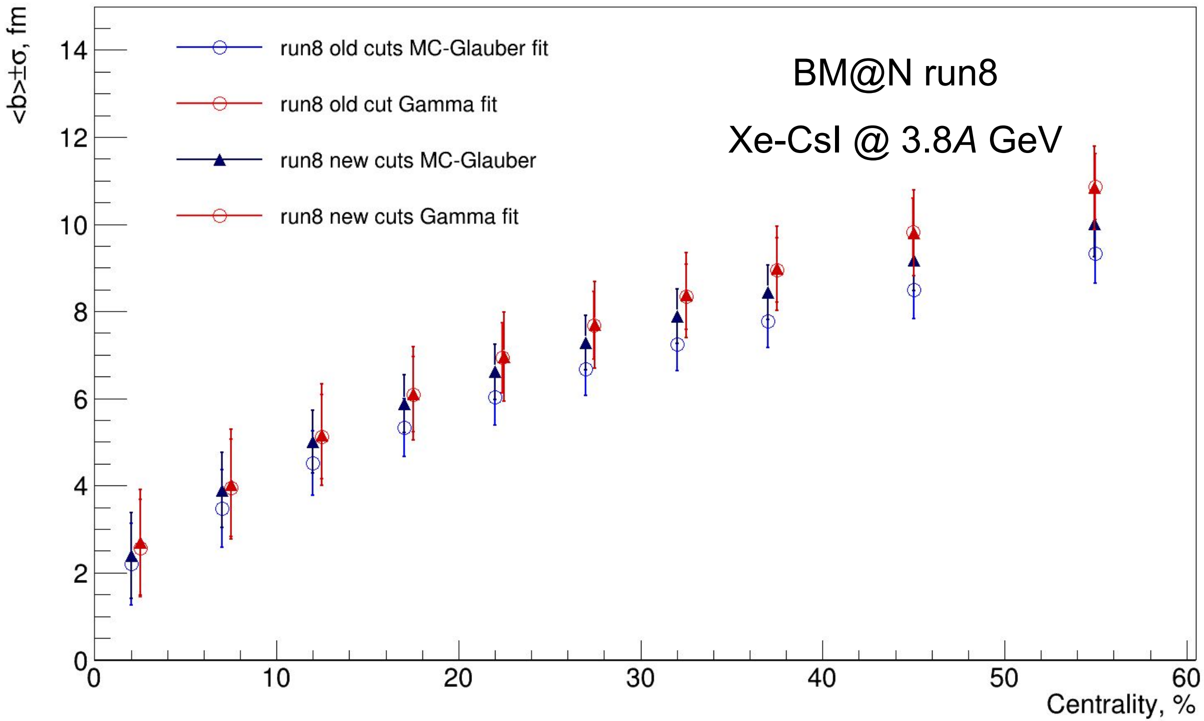
R. Rogly, G. Giacalone and J. Y. Ollitrault, Phys.Rev. C98 (2018) no.2, 024902
Implementation for MPD and BM@N by D. Idrisov: https://github.com/Dim23/GammaFit
Example of application in MPD: **P. Parfenov et al., Particles 4 (2021) 2, 275-287**

Comparison with older results (E_{kin}=3.8 GeV)



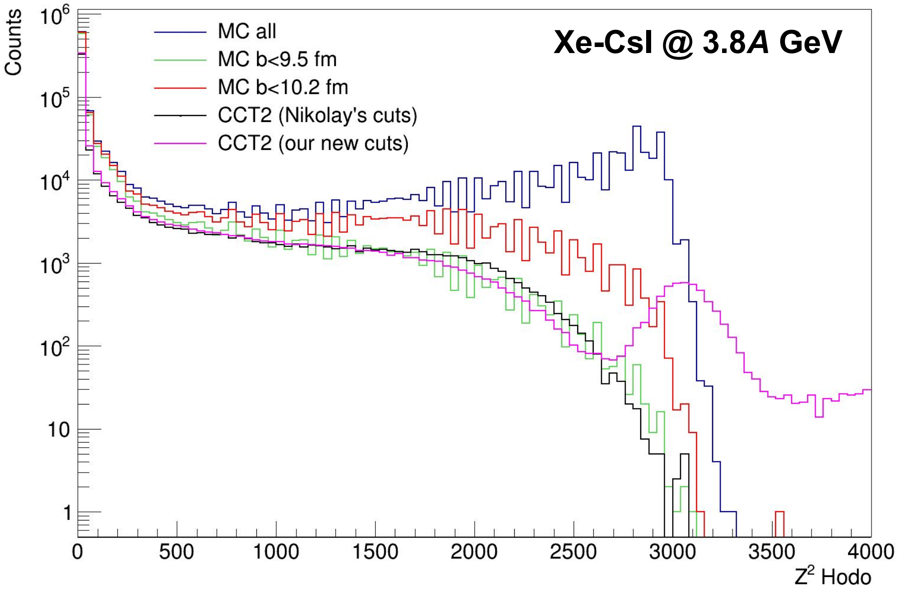
- For the new cuts fit also a little bit better
- These classes can be used during physics analysis
- Trigger efficiency at the peripheral events should be taken into account

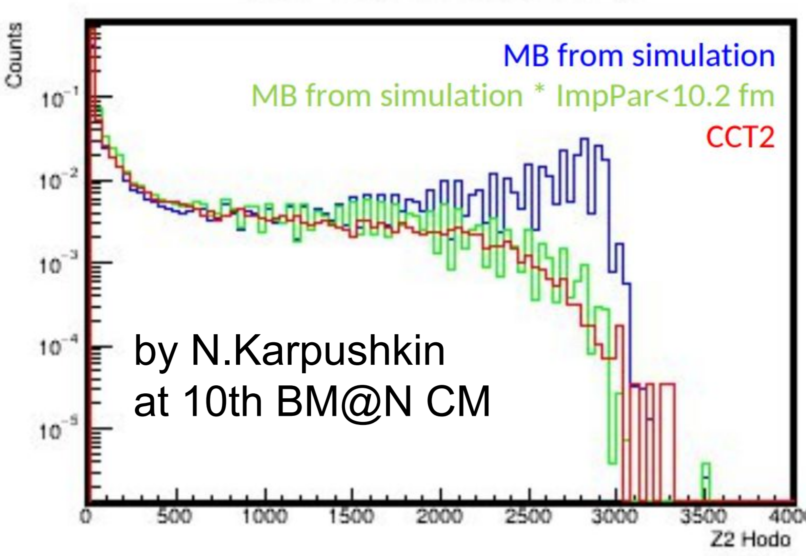
Comparison between impact parameter distributions



- For Γ-fit all centrality classes are comparable
- Γ-fit and MC-Glauber fit are now in more agreement with each other

Estimation of trigger efficiency

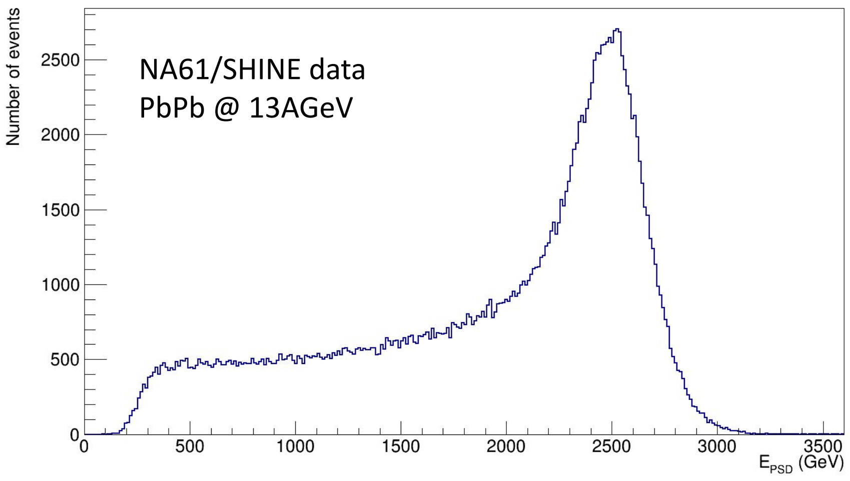


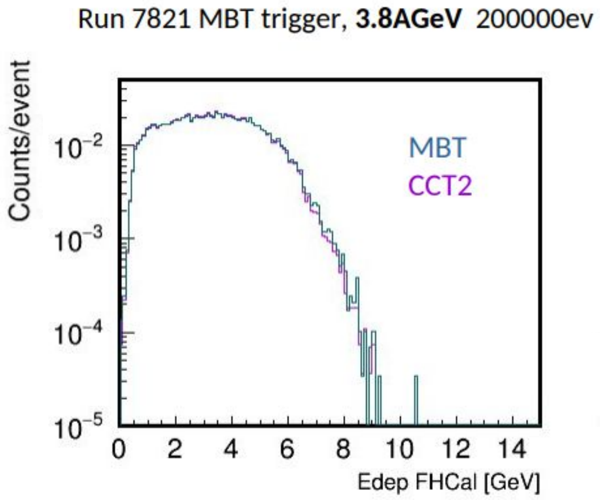


by N.Karpushkin
at 10th BM@N CM

- Results do not agree with Nikolay’s results from the last CM
- Looks like CCT2 trigger has good efficiency for the events with up to 60% centrality

How to reconstruct “real” energy of spectators?

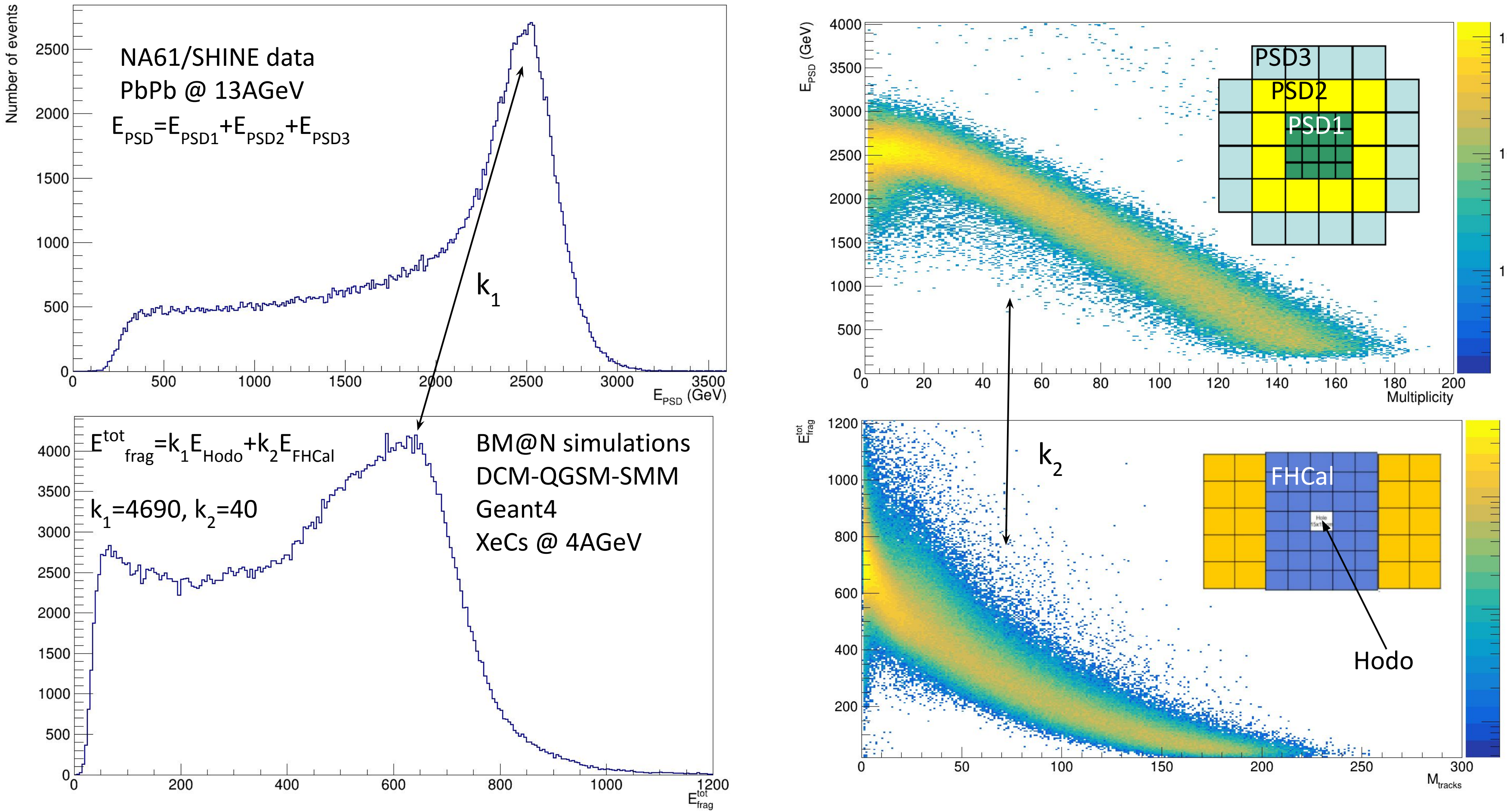




by N.Karpushkin
at 10th BM@N CM

- In the NA61/SHINE experiment the peak of PSD energy distribution is located at E_{beam} * A_{Pb}~2700 GeV
- In our case we don’t see range of energies in FHCal corresponding to collision energy and colliding system
- Is it possible to reconstruct “real” energy of spectators using E_{dep}?
- If so is there any way to do so for Hodoscope?

Possibilities of spectators fragments as estimators



Summary

- Simple steps for the pileup rejection are introduced
- The first version of it is performed

- MC-Glauber and Γ-fit fitting procedures is applied
  for centrality determination for the BM@N run8 data
- Relation between impact parameter and centrality classes is extracted
- These results are used in the physics analysis
- CCT2 trigger efficiency is estimated to be high up to 60% centrality

Work in progress

- Establish the final events selection procedure
- Use spectators detectors for the centrality determination
- Compare centrality classes and geometry parameters corresponding to them
  for different centrality estimators

Backup

Overview of centrality determination methods

Method type	MC-Glauber based	Model independent (e.g. Γ-fit method)	Based on ML
Used in	STAR, ALICE, HADES, CBM, MPD, etc.	ALICE, CMS, ATLAS J. Y. Ollitrault et al. Phys.Rev. C 98 (2018) 024902	Becoming popular Fupeng L. et al. J.Phys.G 47 (2020) 11, 115104
Advantages	Commonly used, well established procedure	Universality due to model independence	The most modern and fast methods
Disadvantages	MC-Glauber model provides non-realistic N_{part} simulations at low energies M. O. Kuttan et al. e-Print: 2303.07919 [hep-ph]	In strong connection with σ_{inel} which dependence on energy is not well studied at low energies (same problem for MC-Glauber based methods)	There no way to control the physicality of the methods

MC Glauber model

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

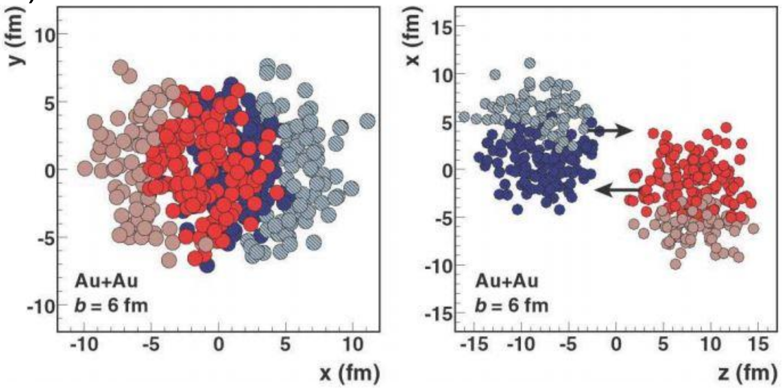
- Independent straight line trajectories of the nucleons
- A-A collision is treated as a sequence of independent binary NN collisions
- Monte-Carlo sampling of nucleons position for individual collisions

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

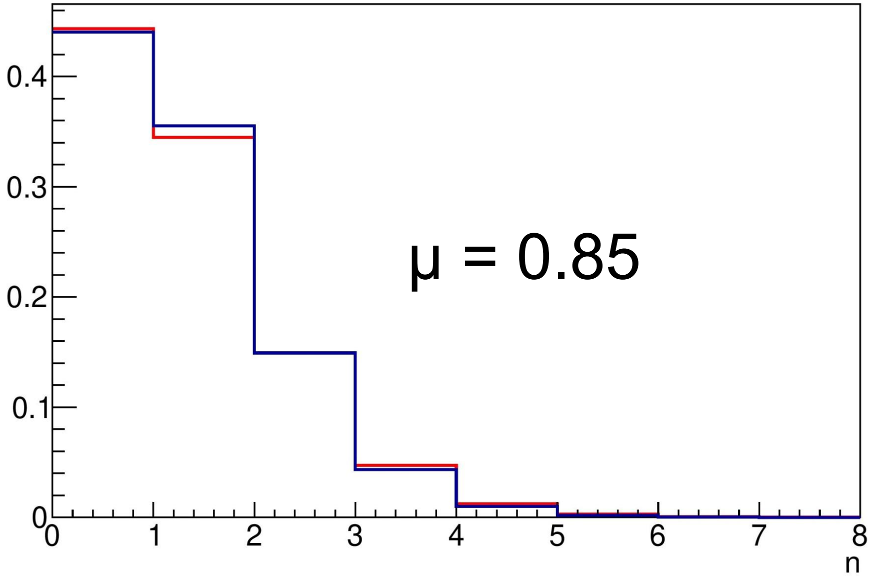
b – impact parameter

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

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

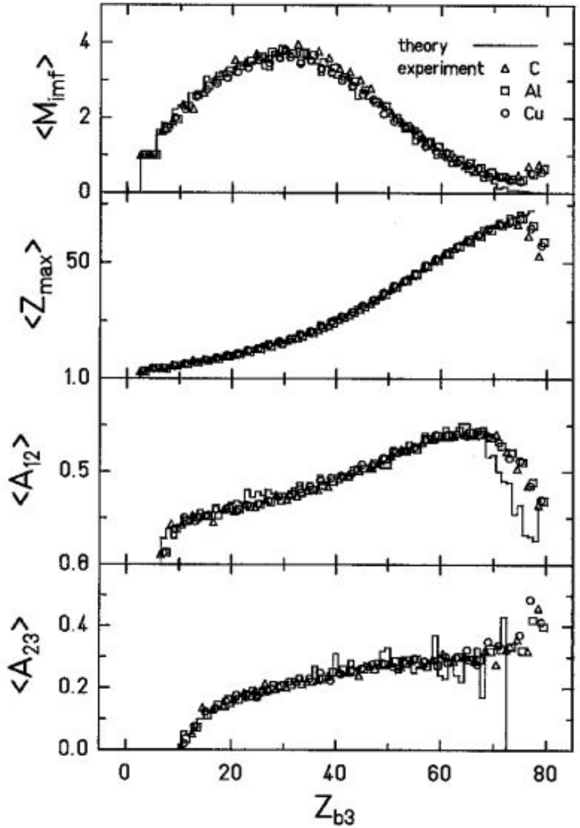
N_{coll} – number of binary NN collisions

NBD at different values of k

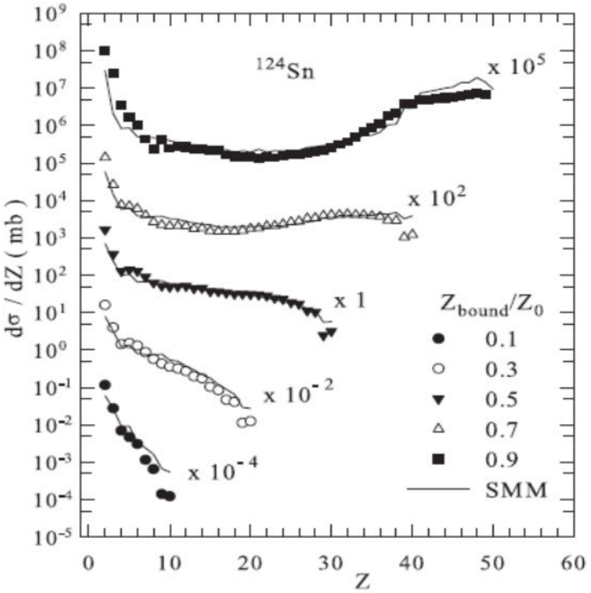


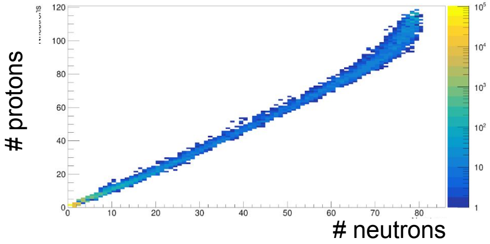
SMM description of the ALADIN's fragmentation data

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

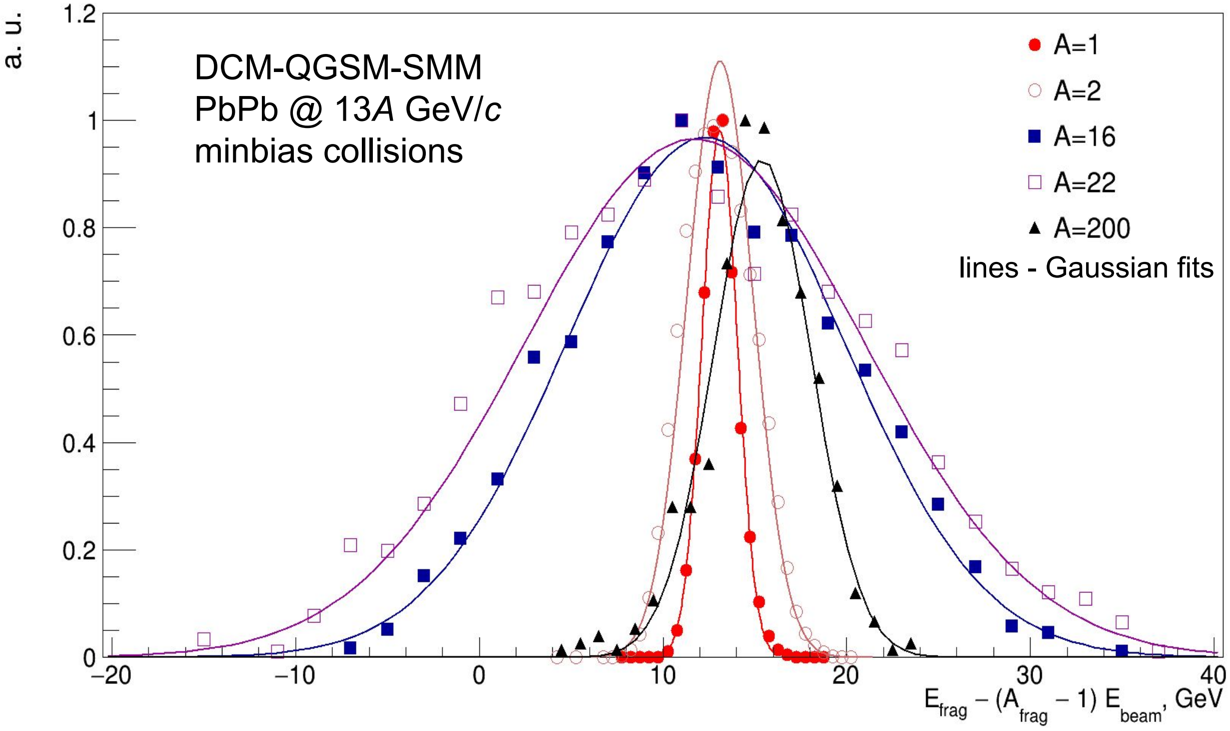


R.Ogul et al. PRC 83, 024608 (2011)





Gaussian approximation for fragments energy

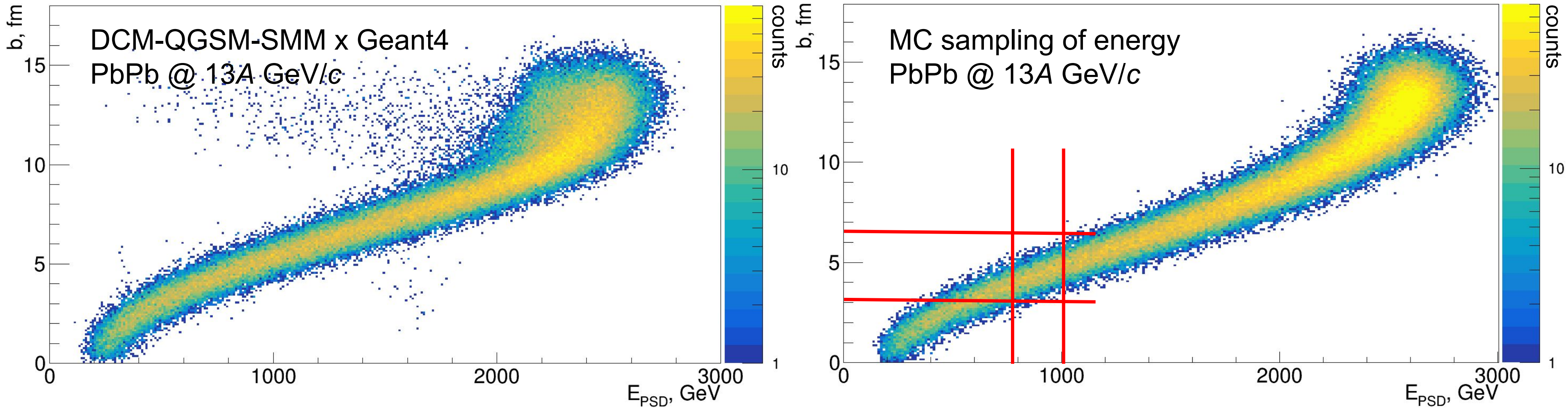


- Distribution of mass numbers of spectators fragments could be fitted by Gauss distribution
- Mean values equal to product of beam energy and fragment's mass
- Total spectators energy distribution is also Gauss:

$$P(E_{tot};\mu_{tot},k_{tot}) \approx \prod_{i=1}^{N_{frag}} P(E^i_{frag};\mu^i_{frag},k^i_{frag}) \approx \prod_{j=1}^{N_{spec}} P(E^j_{spec};\mu_{spec},k_{spec})$$

- Measured energy distribution follows convolution of two Gauss distributions (sum of fragments energy and detector response)

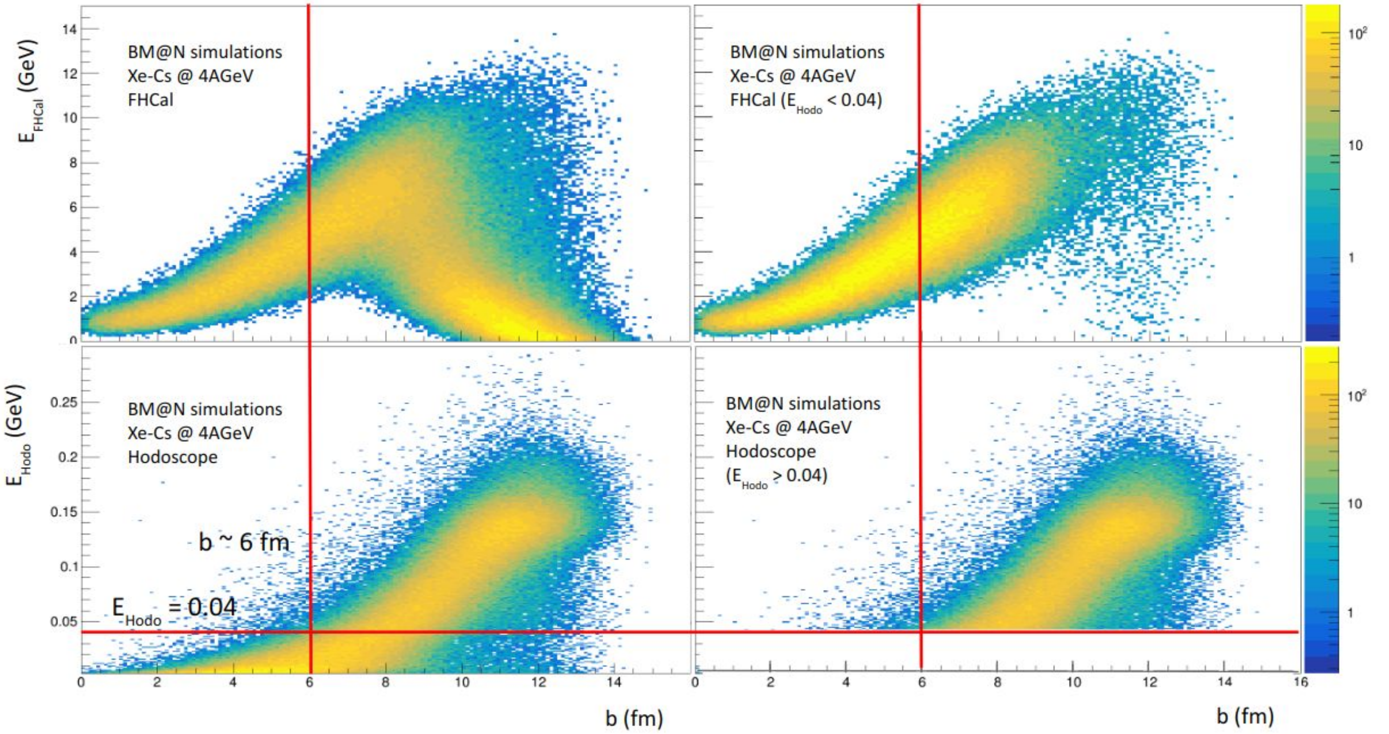
Simplified MC sampling for hadron calorimeters



Segal I. Particles. 2023; 6(2):568-579.

- Shapes of energy and impact parameter distributions are similar
- Width of distribution for energy is larger than for multiplicity
- Possible decrease of width will be study

Possibilities of spectators fragments as estimators



- Physical threshold of switching between estimators could be Hodoscope signal E_{Hodo} = 0.04 (corresponding to b ~ 6 fm)
- FHCal energy distribution improved and has more linear correlation with impact parameter (for range E_{Hodo} < 0.04)
- There is good correlation between Hodoscope charge and impact parameter (for range E_{Hodo} > 0.04)