Global observables in heavy-ion collisions at NICA. PWG1 status report

G. Feofilov, on behalf of the PWG1/MPD team
V.Fock Institute for Physics, Laboratory of Ultra-High Energy Physics, Saint-Petersburg State University

MPD Collaboration meeting ***21.04.2021—23.04.2021, JINR, Dubna***

MPD Physics Programme

G. Feofilov, A. Ivashkin

Global observables

- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

V. Kolesnikov, Xianglei Zhu

Spectra of light flavor and hypernuclei

- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diag.

K. Mikhailov, A. Taranenko

Correlations and Fluctuations

- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

V. Riabov, Chi Yang

Electromagnetic probes

- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

Wangmei Zha, A. Zinchenko

Heavy flavor

- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

PWG1-MPD status

Institutes – participants of the PWG1 activity:

SPbSU (St.Petersburg),

INR RAS (Troitsk, Moscow),

MEPhI (Moscow) and

MexNICA Collaboration (Mexica)

PWG1 co-conveners:

Alexander Ivashkin (INR RAS, RF) ivashkin@inr.ru

Grigory Feofilov(SPbSU,RF) g.feofilov@spbu.ru

Regular meetings in October 2020 –April 2021: 6 PWG1 meetings

https://indico.jinr.ru/category/343/

Conferences: --only RFBR in Oct 2020, https://indico.jinr.ru/event/1469/

Please, visit our PWG1 WEB page: https://indico.jinr.ru/category/343/

➢*Send us an e-mail to join the group!*

Layout of the talk

1) Introduction
2) Two approaches to centrality classes determination:

-- Centrality classes based on charged particles multiplicity

-- Classes with the account of space distribution of the deposited energies in FHCal modules

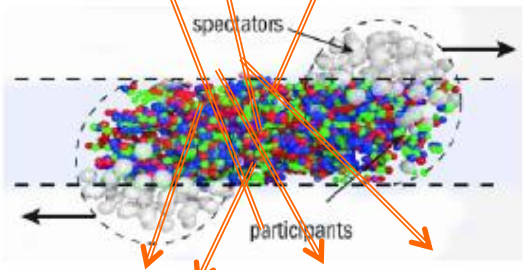
3) Briefly from theoretical modeling of Spectator Matter in Nuclear Collisions at NICA
4) Discussion and Conclusions

Two main approaches to centrality class(es selection:

1) Charged particle Multiplicity classes by the TPC (or…)
and
2) Spectator energy classes by FHCal

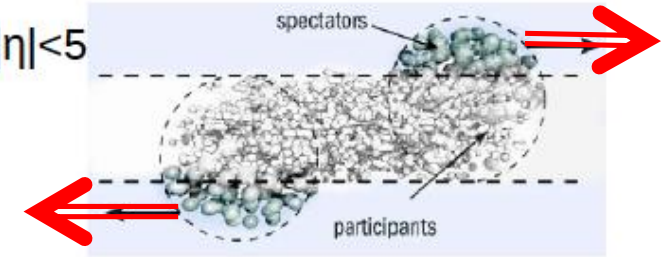
- Time Projection Chamber (TPC)

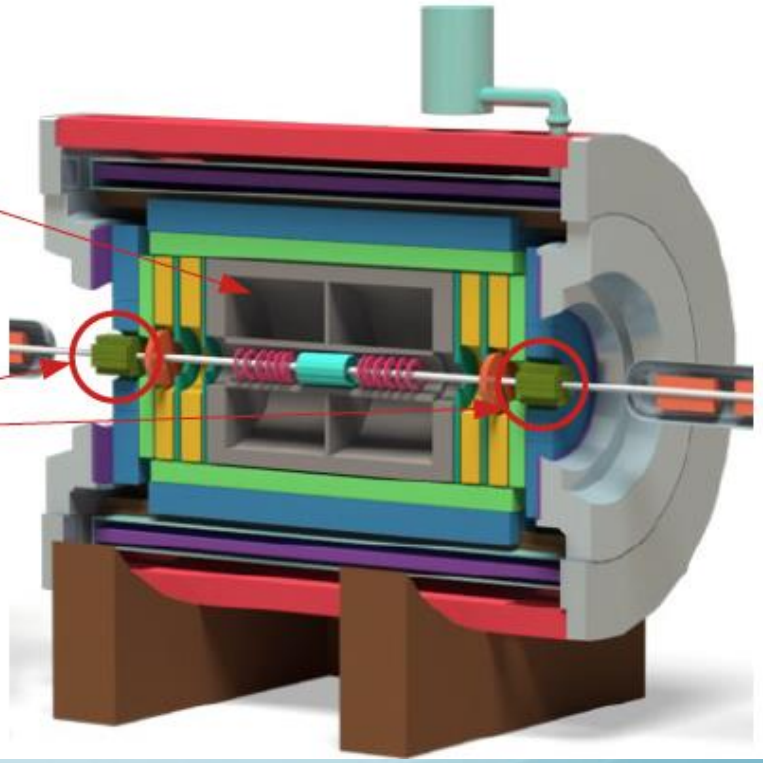
|η|<1.5



- Forward Hadron Calorimeter (FHCal)

2<|η|<5





Two main approaches to determination of classes of centrality

- **Multiplicity in TPC as centrality class estimator**

-- method was suggested by MEPHI/GSI team

Report by Petr Parfenov at the MPD Physics forum 15.04.2021r:

See https://indico.jinr.ru/event/2065/

https://github.com/FlowNICA/CentralityFramework

https://github.com/Dim23/GammaFit

Draft of analysis note:

https://github.com/FlowNICA/CentralityFramework/blob/master/Documentation/Centrality_AnalysisNote.pdf

- **Spectator nucleons with FHCal**

– by the INR RAS team, see the PWG1 meetings Report by Vadim Volkov at the PWG1 meeting **01.04.2021**

https://indico.jinr.ru/event/2066/

or RFBR conference:

https://indico.jinr.ru/event/1469/contributions/9905/attachments/8135/12126/ivashkin_RFBR_2020.pdf

Codes: https://github.com/qweek2/Centrality_NICA/tree/master

The 1st aproach: multiplicity classes

Centrality determination based on charged particle multiplicity

Petr Parfenov, Dim Idrisov, Ilya Segal, Vinh Luong, Arkadiy Taranenko

NRNU MEPhI

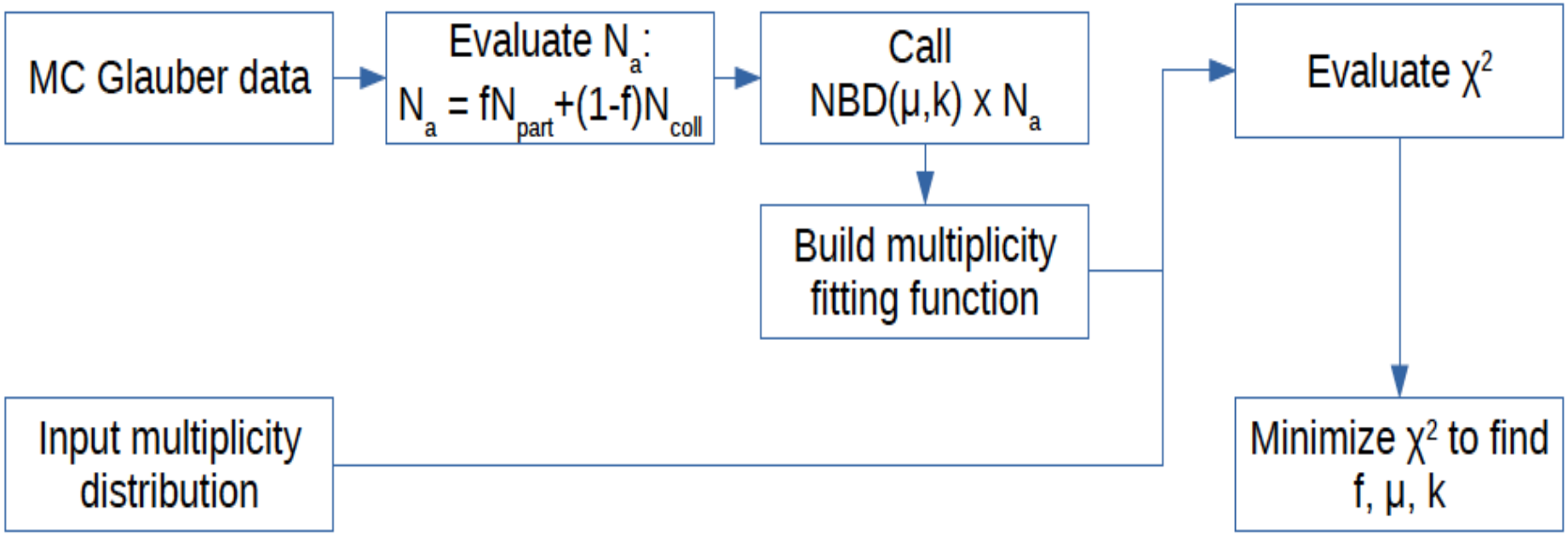
MPD Physics Forum
15 April 2021

This work is supported by:
the RFBR according to the research project No. 18-02-40086 and No. 18-02-40065
the European Union's Horizon 2020 research and innovation program under grant agreement No. 871072

Centrality frameworks: links

- Glauber-based centrality framework (MC-Gl):
  - Git link: https://github.com/FlowNICA/CentralityFramework
  - Manual: https://github.com/FlowNICA/CentralityFramework/blob/master/Documentation/CentralityFrameworkManual_Glauber.pdf
- The Bayesian inversion method (Γ-fit):
  - Git link: https://github.com/Dim23/GammaFit
  - Manual: https://github.com/Dim23/GammaFit/blob/master/Readme.pdf
- Draft of analysis note: https://github.com/FlowNICA/CentralityFramework/blob/master/Documentation/Centrality_AnalysisNote.pdf

Integrating the CBM Centrality framework



This centrality procedure was used in CBM, NA49, and NA61/SHINE:

Acta Phys.Polon.Supp. 10 (2017) 919

EPJ Web Conf. 182 (2018) 02132

Implemantation in MPD: https://github.com/IlyaSegal/NICA

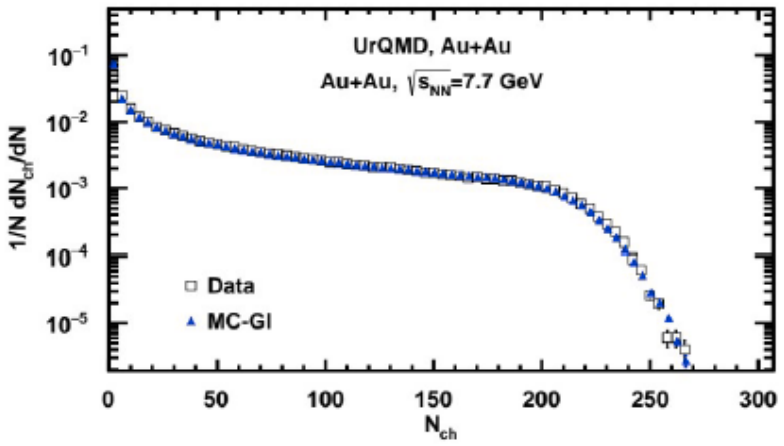
MC-Glauber based centrality framework

MC Glauber data → Evaluate N_a: $N_a = fN_{part}+(1-f)N_{coll}$ → Call NBD(μ,k) x N_a → Evaluate χ^2

Call NBD(μ,k) x N_a → Build multiplicity fitting function

Input multiplicity distribution → Evaluate χ^2

Evaluate χ^2 → Minimize χ^2 to find f, μ, k



NBD – negative binomial distribution
Parameters of the fit:

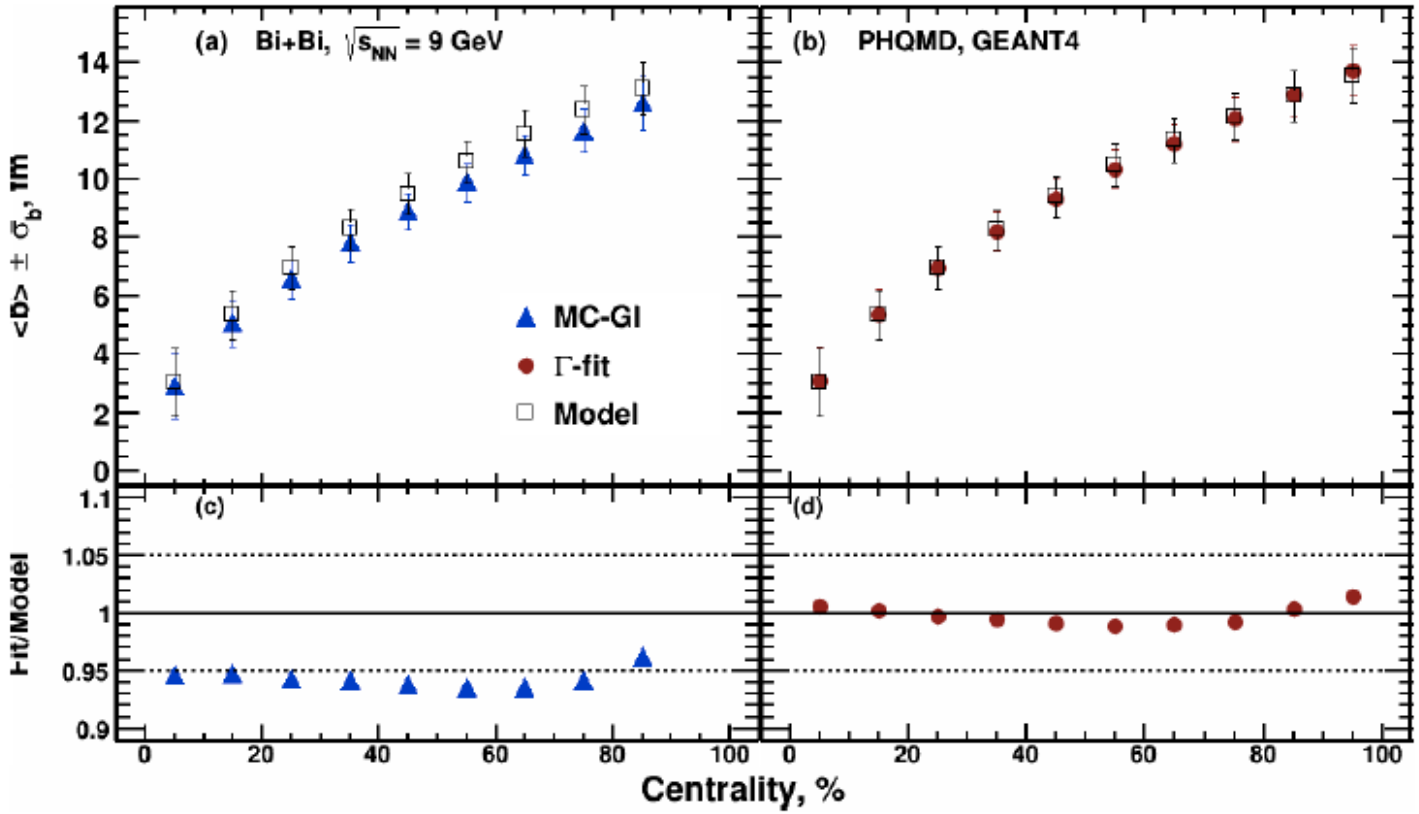
- **f** – fraction of the production from the soft component
- **μ** – mean multiplicity value
- **k** – width of the multiplicity distribution, can be connected to the fluctuations

This centrality procedure was used in CBM, NA49, and NA61/SHINE:

- I. Segal, I. Selyuzhenkov et al., J.Phys.Conf.Ser. 1690 (2020) 1, 012107
- V. Klochkov, I. Selyuzhenkov et al., EPJ Web Conf. 182 (2018) 02132

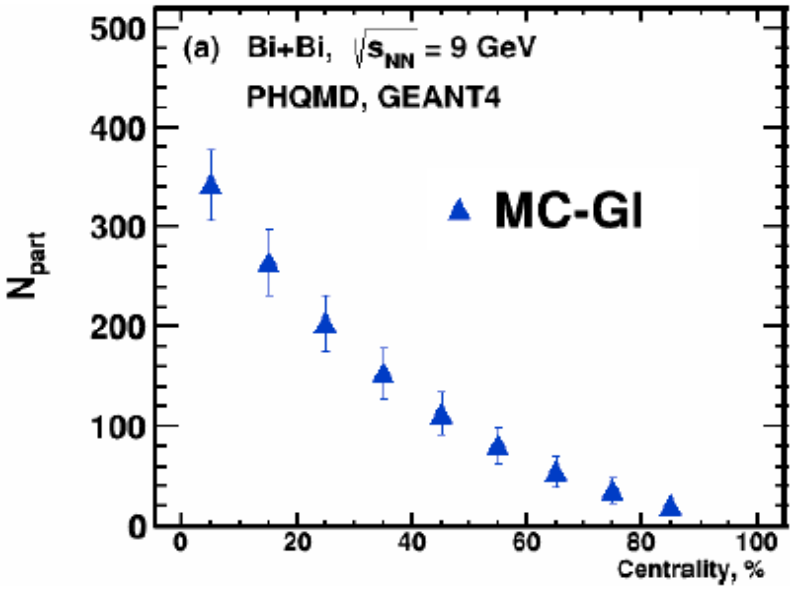
Implemantation for MPD: https://github.com/FlowNICA/CentralityFramework

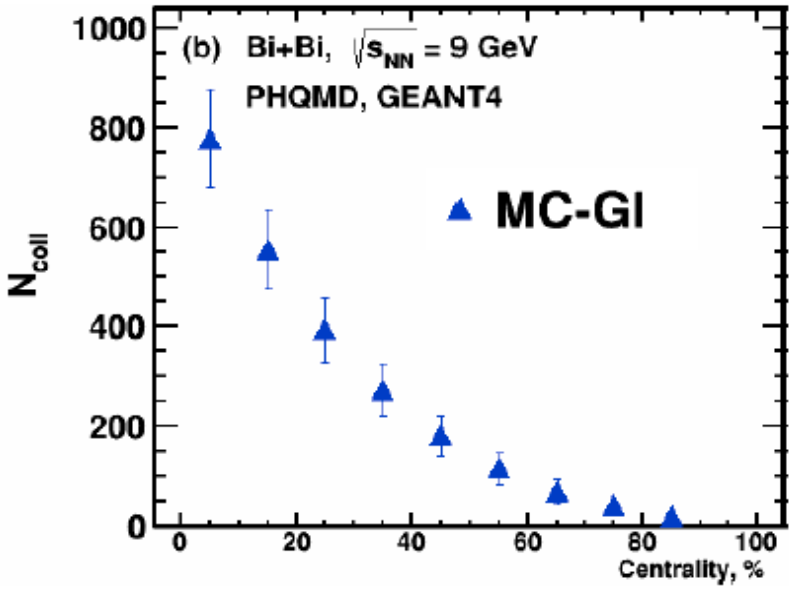
<b> vs Centrality: MC-Glauber



...some examples...

$\langle N_{part} \rangle$, $\langle N_{coll} \rangle$ vs Centrality: MC-Glauber





Summary for Multiplicity method (from talk by Petr)

Summary and next steps

- Centrality determination for UrQMD, AMPT, DCM-QGSM-SMM:
  - Fitted functions from both methods reproduce charged particle multiplicity
  - Extracted relations between impact parameter and multiplicity centrality classes are in a reasonable agreement for both methods and for all given models
- Performance study was done for fully reconstructed data sets within MPDROOT framework:
  - Results are consistent with ones from the models
  - Used primary track selection based on DCA
  - Systematic study shows sensitivity for <b> within 1-3%

The 2nd approach: spectators

Comparison of two methods for centrality measurements in MPD experiment

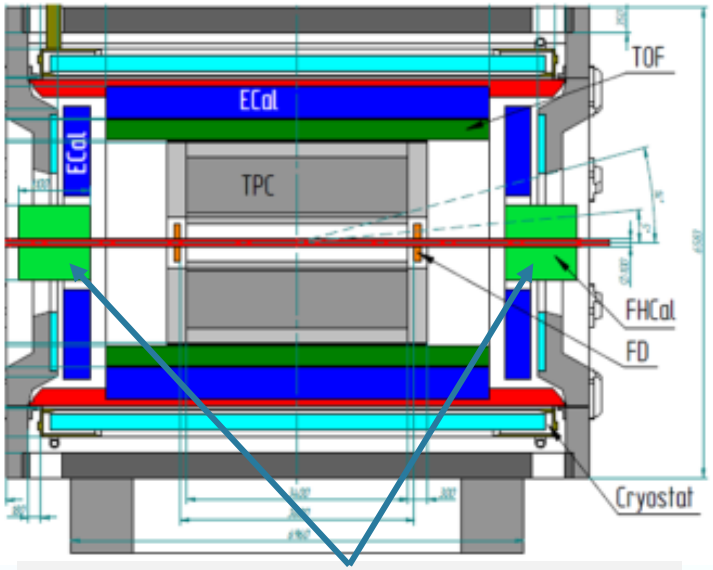
Volkov Vadim

INR RAS

01/04/2021

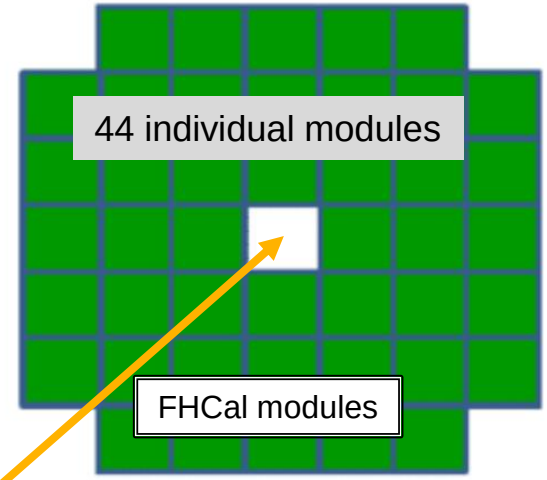
PWG1

FHCal@MPD

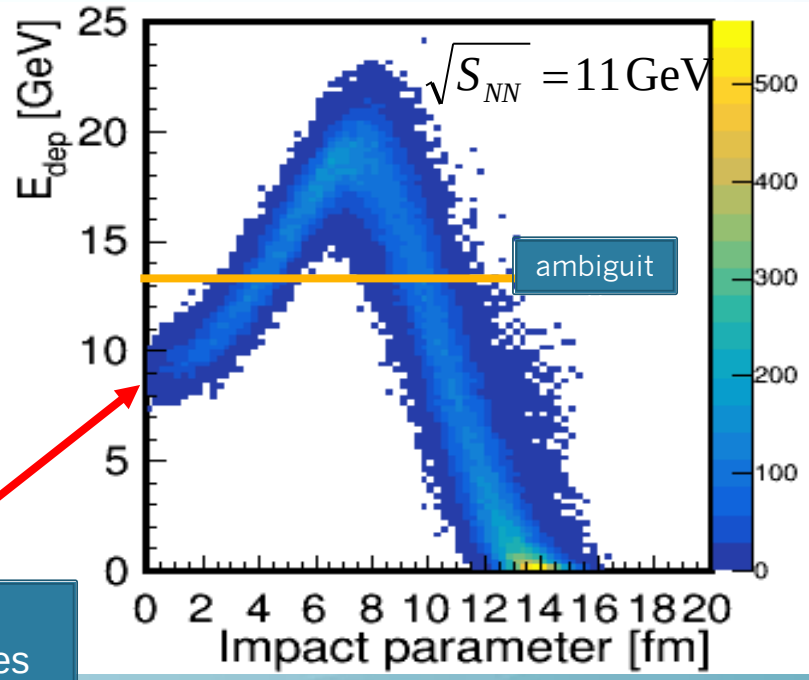


Two upstream/downstream parts

- The main purpose of the FHCal is to detect spectators and to provide an experimental measurement of a heavy-ion collision centrality and orientation of its reaction plane.
- There is an ambiguity in FHCal energy deposition for central/peripheral events due to the fragments (bound spectators) leak into beam hole.
- FHCal measures not only spectator's but also pion's energies.

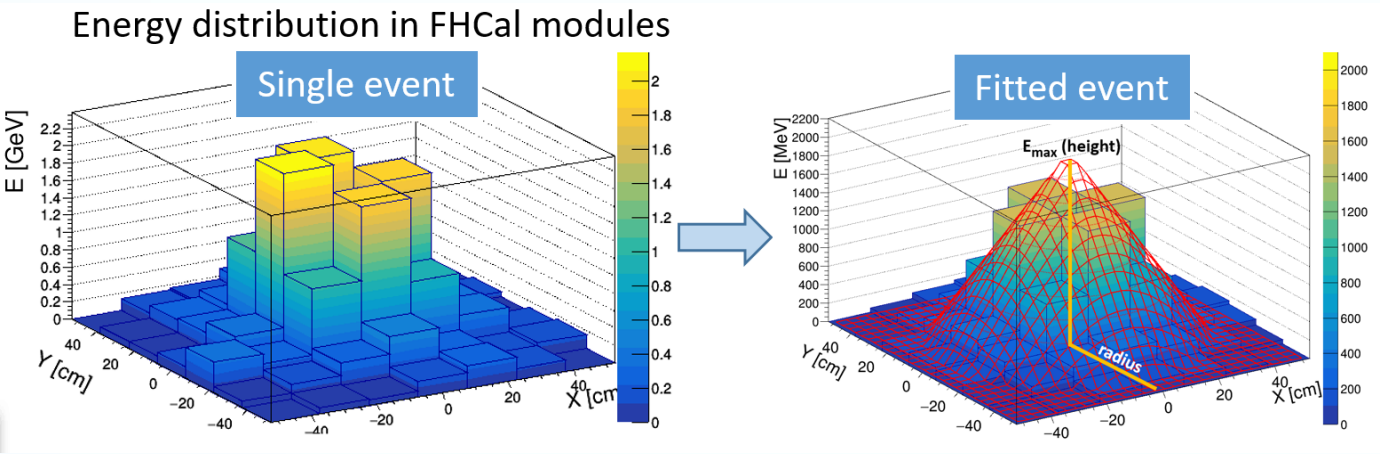


Beam hole



Contributions of produced particles

2D fit method (linear approach)



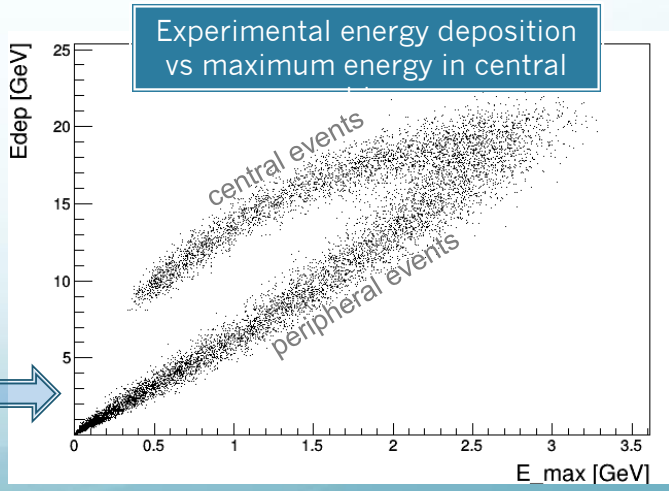
- In this method the space energy distribution in FHCal modules is used.
- The energy in the histogram is uniformly distributed in FHCal modules according to the polar angle.
- The histogram is fitted by a symmetrical cone (linear approximation).
- Weight of each bin is proportional of the energy deposited in corresponding FHCal module.
- This fit provides the new observables: radius, height of the cone. Volume of cone corresponds to the reconstructed energy (E_{rec}).
- https://github.com/qweek2/Centrality_NICA/tree/master

Initially we have experimental energy deposition E_{dep} in FHCal.

After linear fit we have:

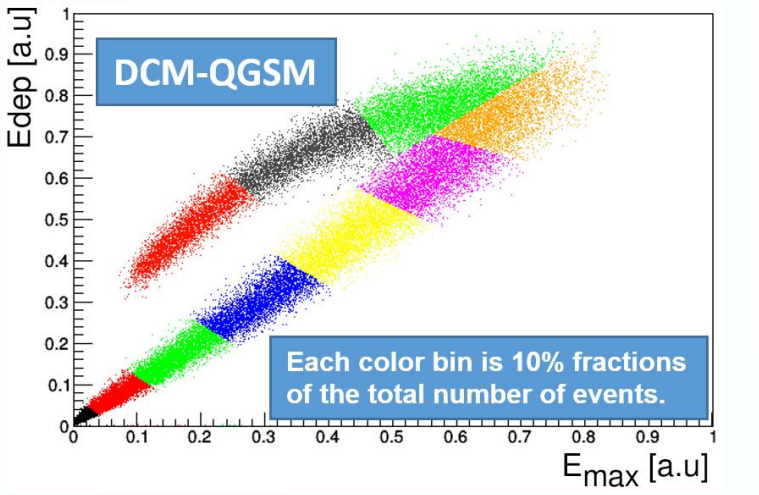
- **E_{rec} is reconstructed energy (volume of cone);**
- **E_{max} – maximum energy in central bin (in FHCal hole);**
- ***Radius* of spectator spot at FHCal is defined by the scattering spot of spectators.**

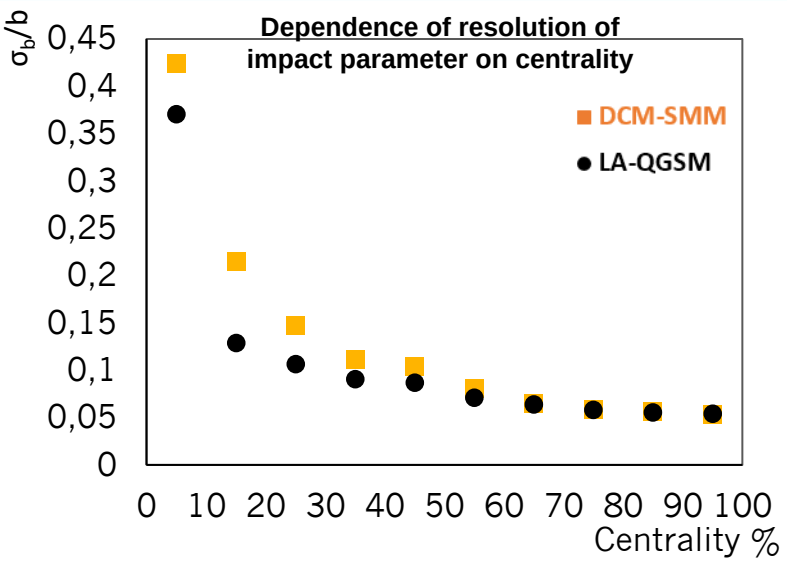
This correlation can be used for the centrality determination



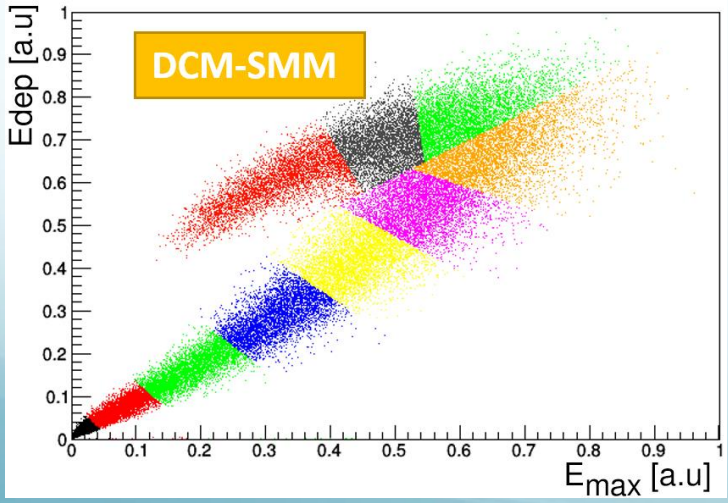
In ideal case all fit parameters may be used for centrality determination

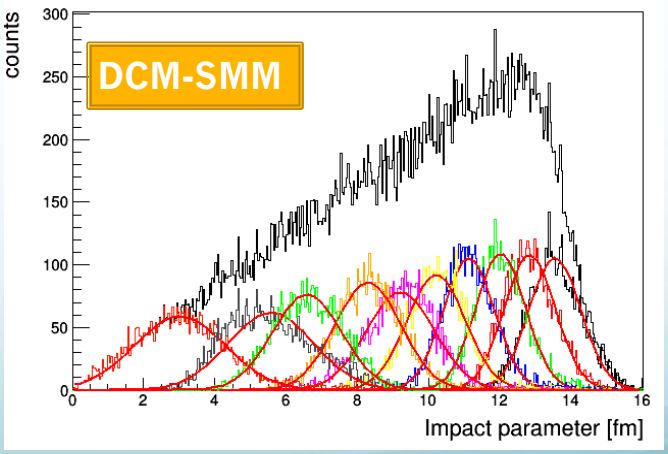
Centrality resolution for E_{dep} vs E_{max}



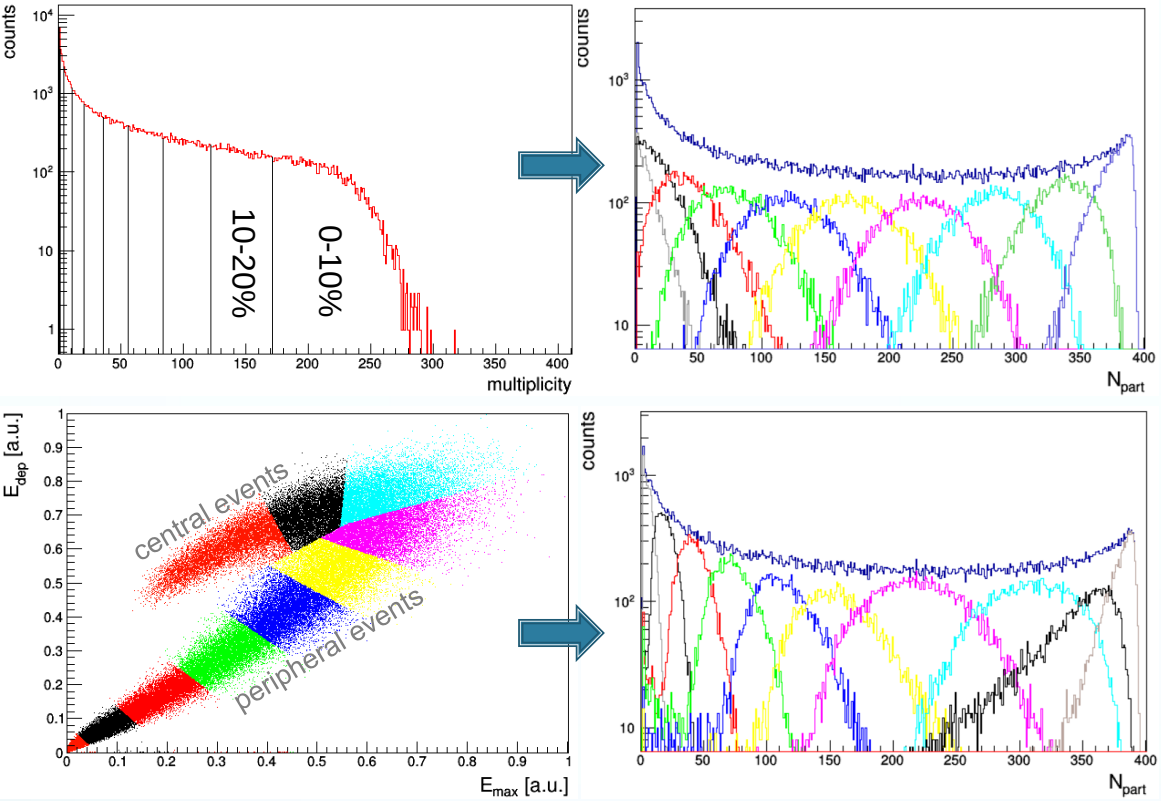


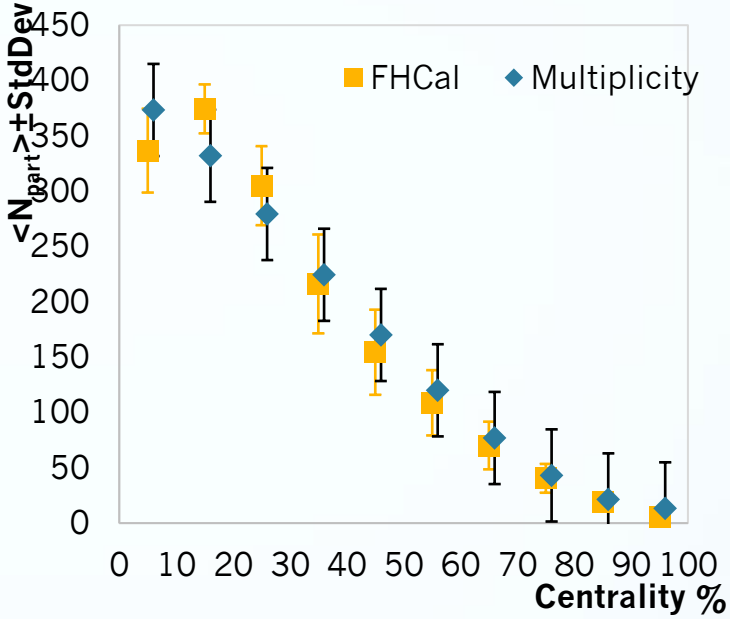
DCM-SMM model provides worse (than DCM-QGSM) centrality resolution because this model has much more heavy fragments which leak in FHCal beam hole.

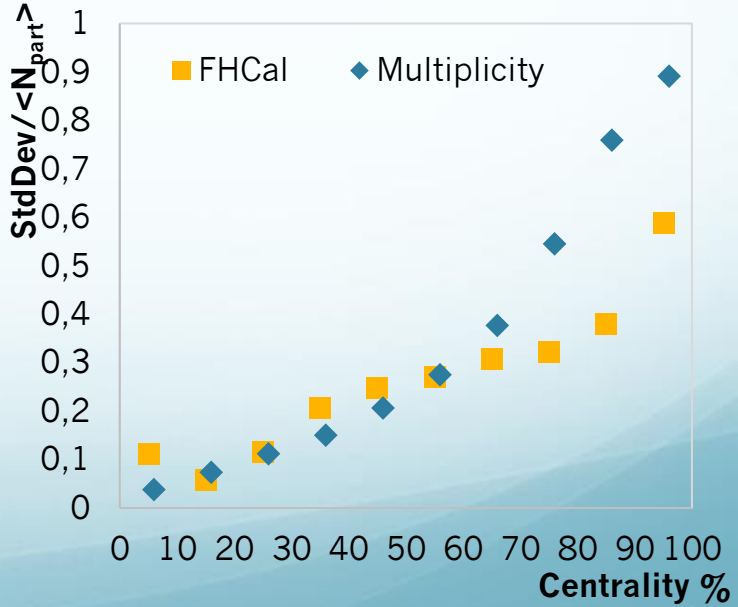




TPC multiplicity vs FHCal classes comparison







Two methods of centrality determination comparison

1. TPC multiplicity bins
2. 2D-Fit

In both cases the participants are taken directly from the DCM-SMM

FHCal gives more accurate results for peripheral events, while for the most central events the accuracy is close and of the order of 15%.

Summary for the 2nd approach

- New approach for the centrality classes determination with spectators energy measurement is under development. It is based on the space distribution of the deposited energies in FHCal modules.
- The results are strongly dependent on the used fragmentation model (DCM-SMM or LA-QGSM).
- Analysis of combined approaches could be promising

Centrality-wise optimization of the class width

Yadernaya Fizika, 2016, Vol. 79, No. 5, pp. 508–519.

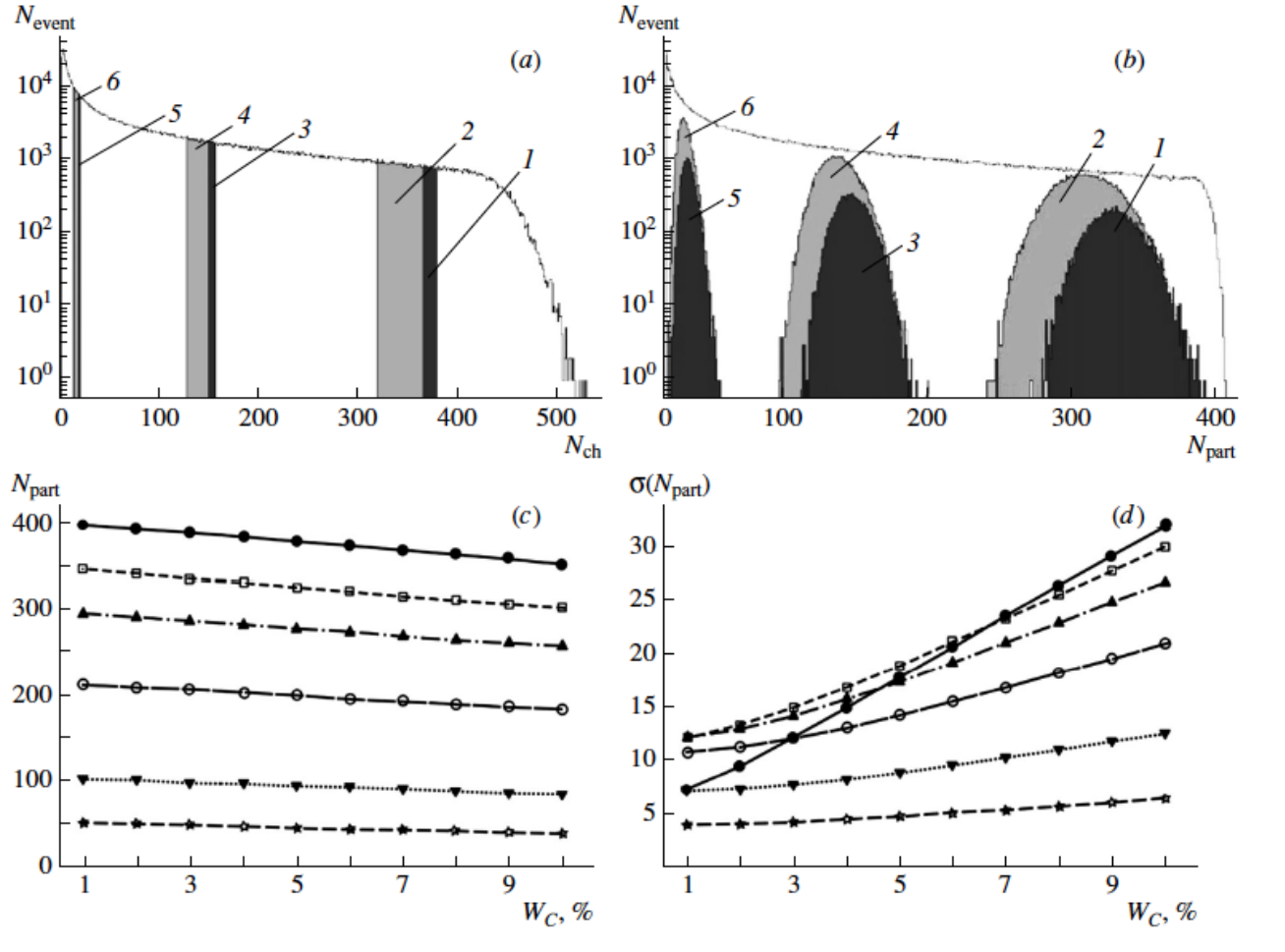


Fig. 1. Distribution of the number of events (N) for PbPb collisions at the c.m. energy of $\sqrt{s} = 2.76$ TeV (calculation on the basis of the Glauber model with the Monte Carlo event generator from [53]) with respect to the (*a*) multiplicity N_{ch} and (*b*) number N_{part} of participant nucleons for the following chosen classes of multiplicity and centrality C: (*1*) 5–6%, (*2*) 5–10%, (*3*) 30–31%, (*4*) 30–35%, (*5*) 70–71%, and (*6*) 70–75%; analogous distributions of (*c*) the mean number of participant nucleons (N_{part}) and (*d*) $\sigma(N_{part})$ for various classes of N_{ch} versus their widths W_C. The points stand for the lower boundaries of the centrality classes C: $C =$ (closed circles) 0%, (open boxes) 5%, (closed triangles) 10%, (open circles) 20%, (inverted closed

Theoretical modelling of spectator matter in nuclear collisions

- **Genis MUSULMANBEKOV** (JINR, LIT), «Modification of hadron properties in a dense and hot baryonic matter» . "Spectator matter in M-C generators DCM-QGSM and DCM-SMM" https://indico.jinr.ru/event/1620/
  Genis Musulmanbekov(JINR, LIT), "On difference between DCM and Glauber model". https://indico.jinr.ru/event/2099/
  - ***see today at 17:00 REPORT BY Genis Musulmanbekov''Two versions of transport code DCM-QGSM''***

- **Igor PSHENICHNOV,** «What can we learn from remnants of spectator matter in central nucleus-nucleus collisions?», ***"Properties of Spectator Matter in Nuclear Collisions at NICA"***

--- just one brief example from the last report, see the next slide

Properties of Spectator Matter in Nuclear Collisions at NICA

I.A. Pshenichnov[1,2,*], N.A. Kozyrev[1,2], R.S. Nepeyvoda[1,2]
A.O. Svetlichnyi[1,2], U.A. Dmitrieva[1,2]

[1]Moscow Institute of Physics and Technology, Dolgoprudny, Russia
[2]Institute for Nuclear Research, Moscow, Russia
*e-mail: pshenich@inr.ru

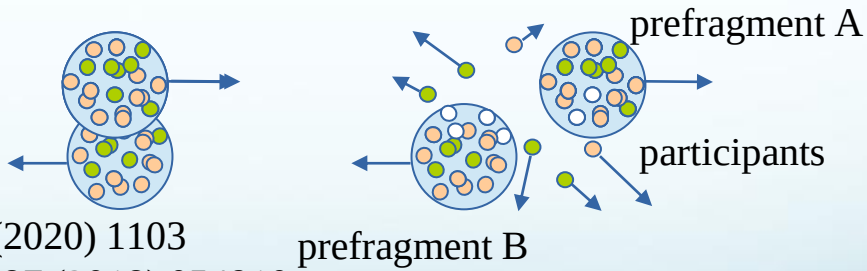
The Conference "RFBR Grants for NICA"
20-23 October 2020
VBLHEP, JINR, Dubna, RUSSIA

AAMCC (or A^2MC^2) model

- Our model **Abrasion-Ablation Monte Carlo for Colliders (AAMCC)**[1] is based on the famous Glauber Monte Carlo version 3[2] and models of decays of excited nuclei from Geant4 toolkit[3] (G4Evaporation, G4SMM, G4FermiBreakUp).
- A difference in proton and neutron density distributions in colliding nuclei is taken into account in GlauberMC v.3
- We tested and improved[4] G4SMM ($E^*/A_{pf} > 3$ MeV) and G4FermiBreakUp (the latter is for explosive decays of $Z < 9$, $A < 19$ nuclei).
- A key ingredient of the model is the calculation of the excitation energy of prefragments. Either Ericson[5] formula (based on level densities in initial nuclei) or a phenomenological approximation based on ALADIN data[6] is used.

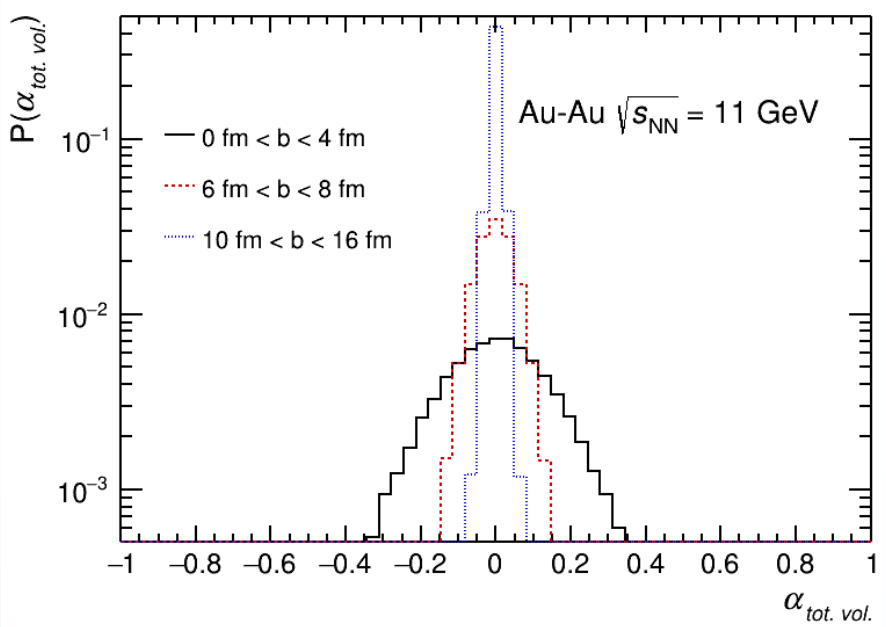
Both prefragments are modelled.

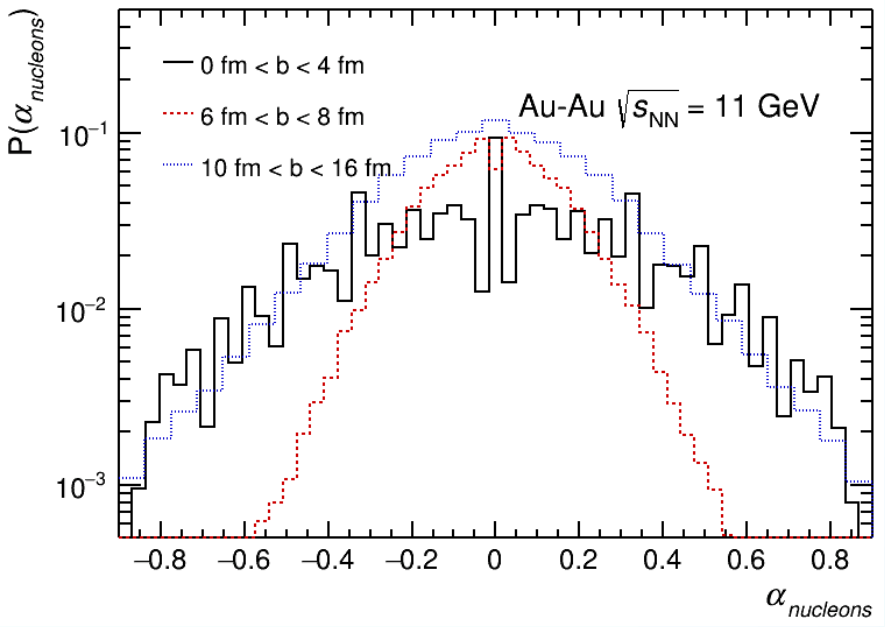
AAMCC is suitable for colliders.



- [1] A. Svetlichnyi, I.P. Bull. RAS: Phys. **84** (2020) 1103
- [2] C. Loizides, J.Kamin, D. d'Enterria, PRC **97** (2018) 054910
- [3] J.M. Quesada,V. Ivanchenko, A. Ivanchenko et al., Prog. Nucl. Sci. Tech. **2** (2011) 936
- [4] I.P., A.S. Botvina, I. Mishustin, W. Greiner, NIMB **268** (2010) 604
- [5] T. Ericson, Adv. Phys. 9, 425 (1960).
- [6] A.S. Botvina et al., NPA **584**, 737 (1995)

Asymmetry of the total spectator volume and of free spectator nucleons





- The total spectator volumes (=A_{pf}) includes all
- nuclear fragments and nucleons
-
- Asymmetry decreases from central to peripheral collisions.

- Only small parts of large spectator volumes are affected by fluctuations in numbers of participants.

- This effect is of trivial statistical nature.

- The dependence on *b* is not monotonic

- The stochasticity of nucleon evaporation in peripheral events adds extra fluctuations.

- **According to AAMCC, events with low nucleon asymmetry can be classified with confidence as semi-peripheral events.**

Summary-1

- Two approaches, are being developed for determination of centrality classes in AA collisions:
  (i) traditional multiplicity-based, and
  (ii) novel approach, based on spectators spatial distributions in FHCal

- Theoretical considerations aimed at ***physics description of*** fragmentation processes ***in AA collisions*** and for understanding of the collision dynamics, are also in progress. An additional observable for centrality classes is proposed: ***a ratio of*** (a sum of fragment charges}^{2}/{total Spect.Energy}.

- Selecting multiplicity classes, as a proxy to centrality in heavy-ion collisions, is needed at the first stage of MPD data analysis to compare with the already existing results obtsained at RHIC.

- Codes for selecting events for classes for multiplicity are developed and accessible. Documentation is also provided (however, the working groups must interact closely with the PWG1)

Summary-2

- The choice of classes on the energy of spectators in the FHCAL calorimeter ---- the procedure is demonstrated based on the newly developed approach of accounting not only energy, but also the spatial distribution of energy of spectators hitting the calorimeter.
- This new FHCAL technique provides an independent selection of classes of events (and it excludes also autocorrelations in the analysis of data on fluctuations and correlations of observables).
- Some problems relevant to the centrality classes selection are revealed:
  -- The events with a rather wide set of impact parameters could be mixed into the class. The trivial volume fluctuations are to be minimized by centrality-wise optimization of the class width used. --The number of binary collisions obtained in a standard Glauber approach is usually model biased (e.g. Glauber). It should be taken into account in the MPD data physics analysis.

Thank you for your attention!

Some comments to Multiplicity-based methods

- Very detailed analysis +documentation in two approaches
- Important for comparison with RHIC data

... but :

- It is used currently at midrapiidty $|\eta|<0.5$ (– self-correlations might be possible in the following analysis). Different pseudorapiditty intervals should be selected^
- Three parameters (f, μ, k)...
- Constant width for all centrality classes (should be optimized)
- Systematic errors and effects of various cuts on multiplicity distribution....
- Glauber-based approach produces noticeble bias to the number of binary collisions Ncoll....it is the old problem

PWG1 reports at conferences in 2020

ICPPA-2020:

Vadim VOLKOV, Approaches in centrality measurements of heavy ion collisions with forward calorimeters at MPD/NICA facility,

Nikolay KARPUSHKIN, Application of Machine Learning methods for centrality determination in heavy ion reactions at the BM@N and MPD@NICA

NUCLEUS 2020:

Vladislav SANDUL, "MC simulations of beam-beam collisions monitor for event-by-event studies at NICA» ,

Alexander IVASHKIN, «Physics with spectators in MPD/NICA experiment»

Genis MUSULMANBEKOV, «Modification of hadron properties in a dense and hot baryonic matter»

Igor PSHENICHNOV, «What can we learn from remnants of spectator matter in central nucleus-nucleus collisions?»

Vladimir ZHEREBCHEVSKY, «Silicon pixel detectors for the Inner Tracking System of MPD experiment at the NICA collider»

RFBR grants for NICA:

Grigory FEOFILOV, Investigation of initial states and development of methods for their analysis in proton and nuclear collisions at energies of the NICA collider.

Vladimir VECHERNIN, “Clusters of cold dense nuclear matter and their registration with the MPD vertex detector. “

Vladimir ZHEREBCHEVSKY,«Detection methods and data analysis for silicon pixel vertex detectors for the experimental set-ups of the NICA complex»

Alexander IVASHKIN, «Measurements of spectators with forward hadron calorimeter at MPD/NICA experiment”

Vera ERMAKOVA , "Stopping of protons in pA collisions at SPS and NICA energies in analytical hydrodynamic model and in SMASH event generator"

Ivonne MALDONADO, “Hyperons in Bi+Bi collisions at MPD-NICA: Preliminary analysis of production at generation, simulation and reconstruction level”

Igor PSHENICHNOV, «***Properties of Spectator Matter in Nuclear Collisions at NICA”***

- **SOME HIGHLIGHTS ARE PRESENTED BELOW:**

PWG1 meetings in October 2020-April 2021

1 October 2020 Talks approval session
https://indico.jinr.ru/event/1600/

- Vladimir Zherebchevsky (Saint-Petersburg State University) , «Silicon pixel detectors for the Inner Tracking System of MPD experiment at the NICA collider» and “Detection methods and data analysis for silicon pixel vertex detectors for the experimental set-ups of the NICA complex»
- Dr Genis Musulmanbekov (JINR, LIT), “Spectator matter in M-C generators DCM-QGSM and DCM-SMM”
- Grigory Feofilov (Saint-Petersburg State University), “Investigation of initial states and development of methods for their analysis in proton and nuclear collisions at energies of the NICA collider.”

PWG1 meetings in October 2020-April 2021

8 October 2020 Talks approval session

https://indico.jinr.ru/event/1620/

- Dr Genis Musulmanbekov (JINR, LIT), “Spectator matter in M-C generators DCM-QGSM and DCM-SMM”

12 November, Meeting on Be-Be detector issues

https://indico.jinr.ru/event/1689/

- Discussion of Be-Be proposal by MexNICA

PWG1 meetings in October 2020-April 2021

17 December 2020,
https://indico.jinr.ru/event/1771/

- G.Feofilov, A.Ivashkin, PWG1 plans for 2021
- Alexey Aparin "A brief overview of requirements on centrality classes by different PWG groups"

01 April 2021
https://indico.jinr.ru/event/2066/

- Vadim Volkov (INR RAS) , "Comparison of two methods for centrality measurements in MPD experiment"

15 April 2021,
https://indico.jinr.ru/event/2099/

- Genis Musulmanbekov(JINR, LIT), "On difference between DCM and Glauber model".