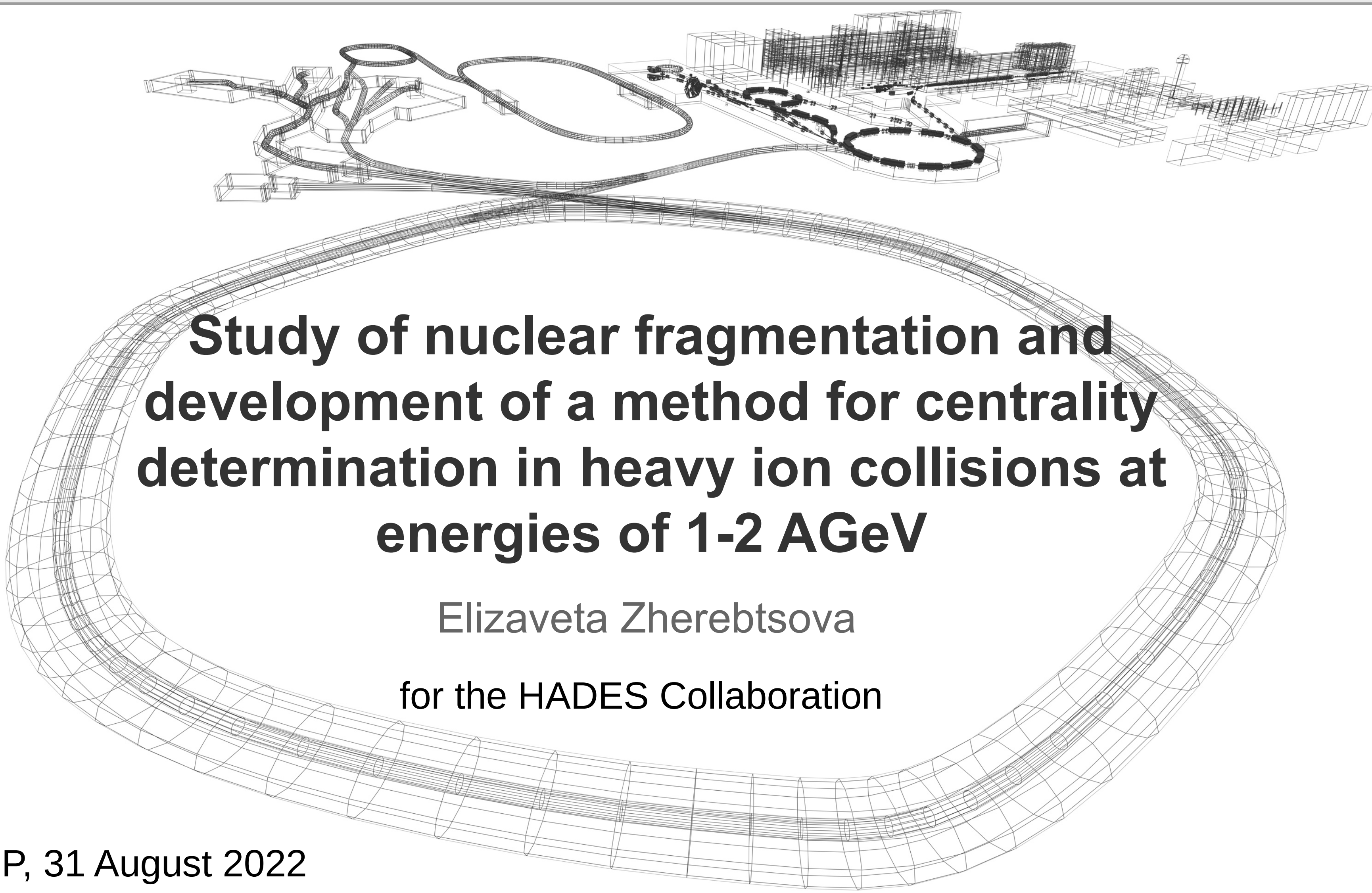


Study of nuclear fragmentation and development of a method for centrality determination in heavy ion collisions at energies of 1-2 AGeV

Elizaveta Zherebtsova

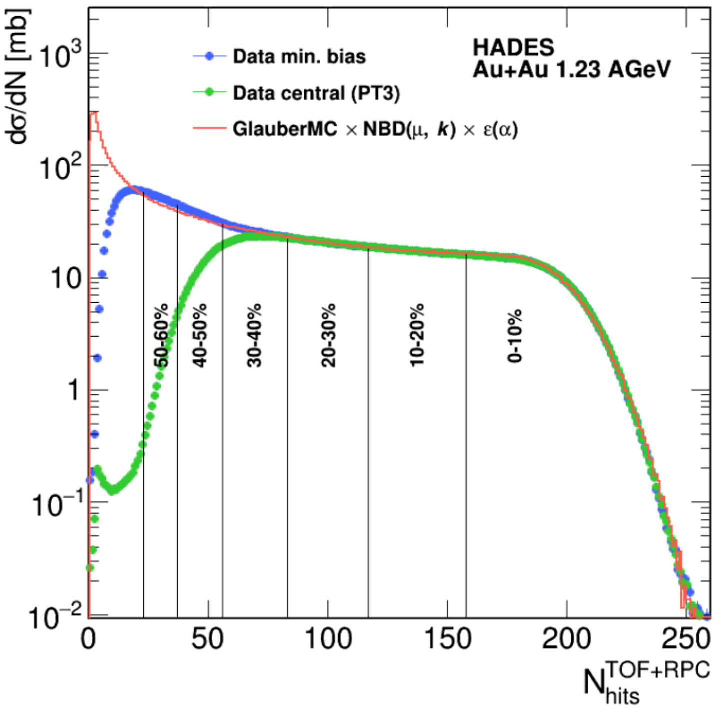
for the HADES Collaboration

ICNFP, 31 August 2022

Outline

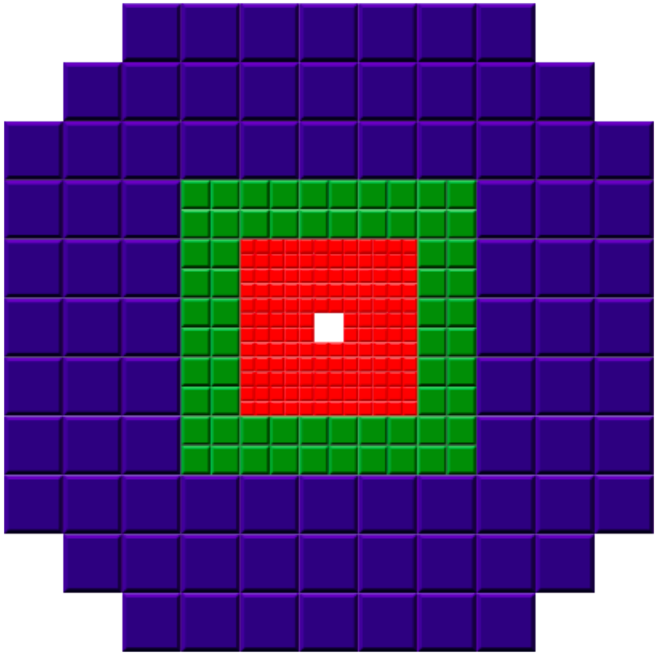
- Motivation
- HADES experimental setup
- FWall construction
- Parameterization of simulated data
- Centrality determination
- Fragmentation: PHQMD & SMASH

Motivation – Part I



- Centrality determination in HADES is based on the Glauber approach using multiplicity of produced particles

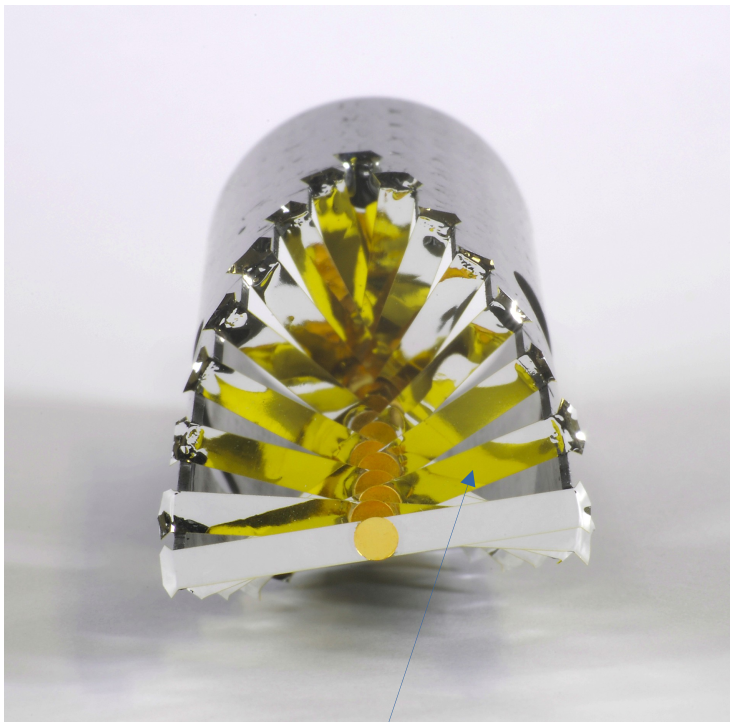
HADES Collaboration, arxiv:1712.07993

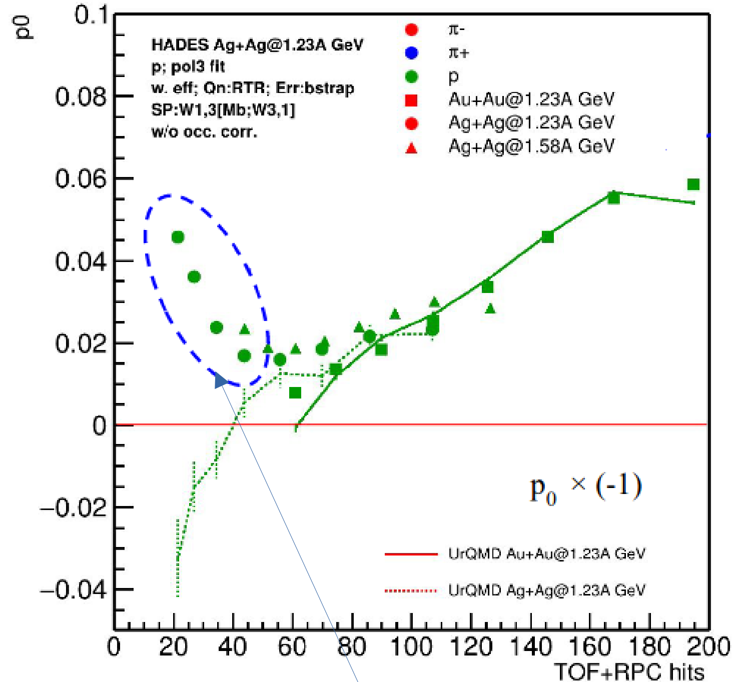


- Forward Wall in the HADES experiment measures the charge of spectators
- Spectators can be used for centrality selection as independent tool
- In order to perform centrality determination based on spectators it needs to have a model, which can describe the FWall distributions

Motivation – Part II

M.Mamaev



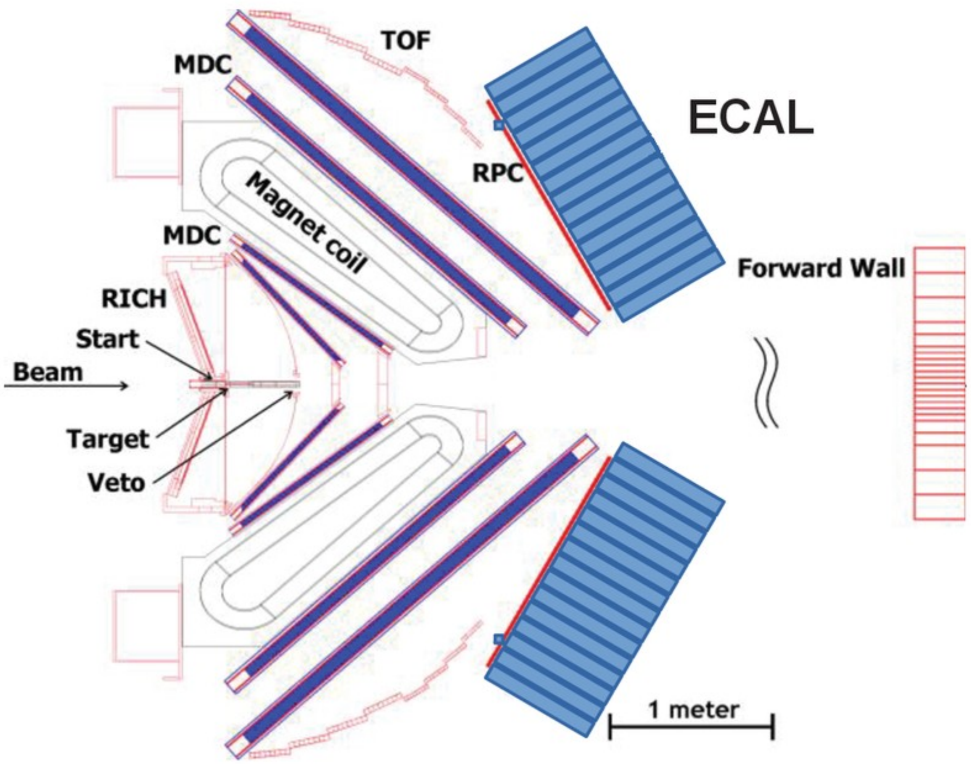


Kapton foils

Carbon contamination

Due to the target constructions, in HADES data there are interactions of beam with carbon in the target substrate.

HADES experimental setup



- Fixed target experiment at SIS18, Darmstadt
- Covers full azimutal angle and 18° < θ < 85° polar angle

Tracking system:

- Multi-wire drift chambers (MDC)

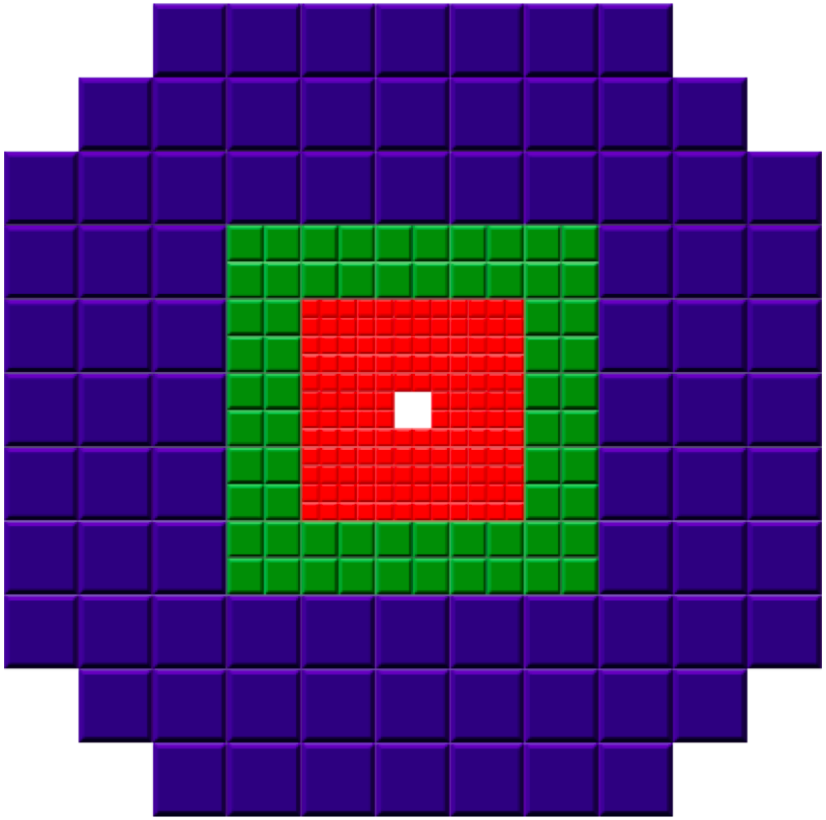
Particle identification:

- Time Of Flight (TOF)
- Resistive Plate Chambers (RPC)
- ECAL

Event plane reconstruction:

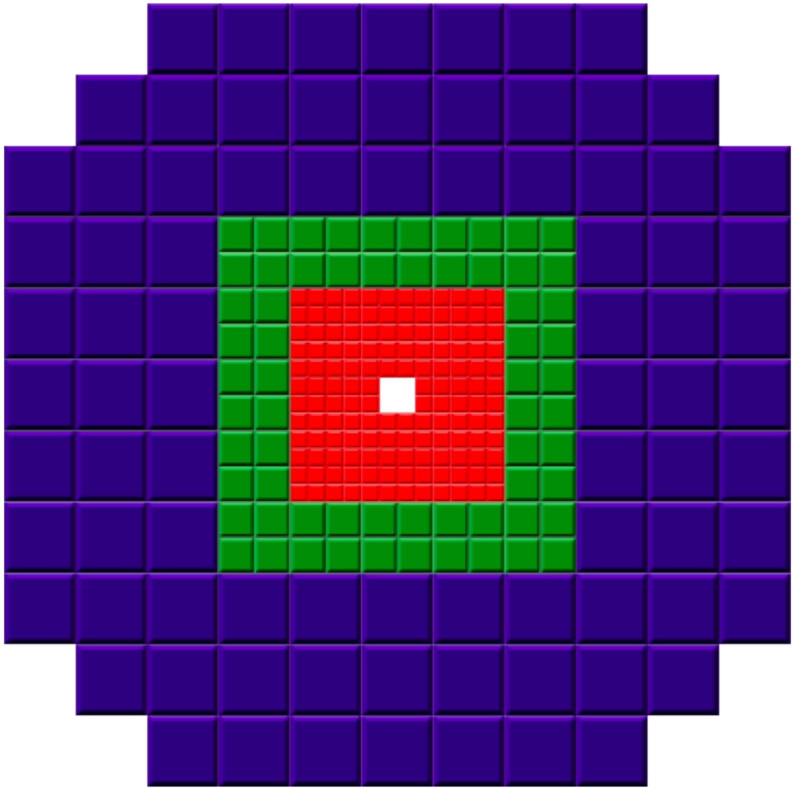
- Forward Wall (FWall)

FWall construction



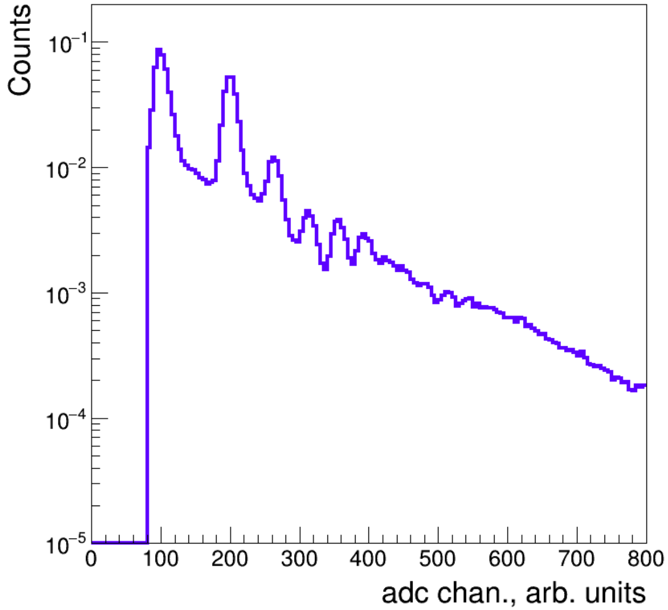
- Forward Wall measures the charge of particles
- The radiations are made of BC408 polystyrene based plastic scintillators
- 7 m behind the target downstream of the beam, a hole 80x80 mm^2
- Covered the polar angle region between 0.33° and 7.17°
- 288 individual scintillators:
  - 140 **small cells** 40x40 mm^2
  - 64 **medium cells** 80x80 mm^2
  - 84 **large cells** 160x160 mm^2

FWall construction & Inefficiency study



Forward Wall signal in experimental data was calibrated as follows:

- Z=1 particles corresponds 100 channel
- Z=2 particles corresponds 200 channel
- Z=3,4.. shifted to the left from 300, 400 etc



Analyzed data & Selection criteria

Collision systems	Au+Au at 1.23AGeV Ag+Ag at 1.58AGeV Ag+Ag at 1.23AGeV
Models	DCM-QGSM-SMM SHIELD PHQMD+MST PHQMD+SACA SMASH
Transport code	GEANT3
Framework	HYDRA
Event selection	Exp. data: PT3 or PT23 trigger Simulation: centrality selection with TOF+RPC hits

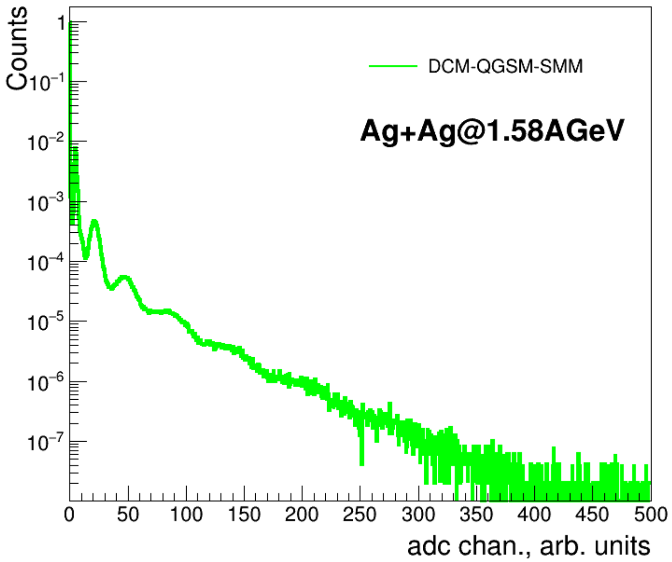
FWall selection:
Amplitude of the signal in each cell > 88
Time of each FWall hit [23.5, 27.5]

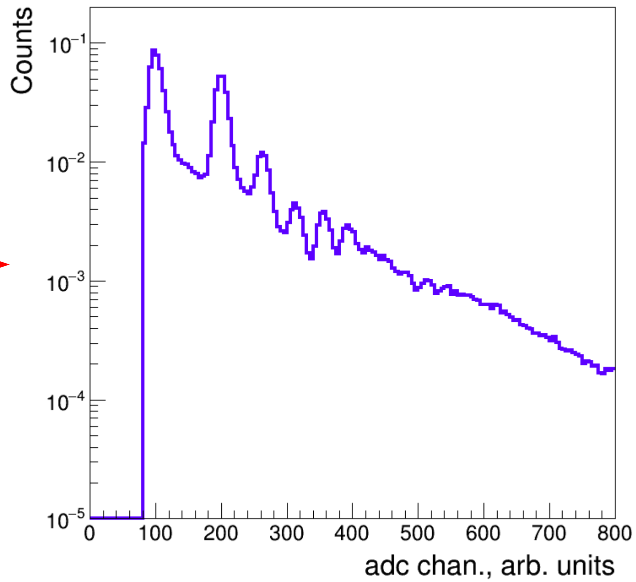
Parameterization of simulation data

Experimental data of the FWall was calibrated in the following way:

- Particles with Z=1 should be in 100 channel, Z=2 in 200 channel.
- Due to this reason it is necessary to make a parametrization of the raw spectra in simulation to have peaks in the same positions as in exp. data

It was developed a procedure to convert raw simulated charge

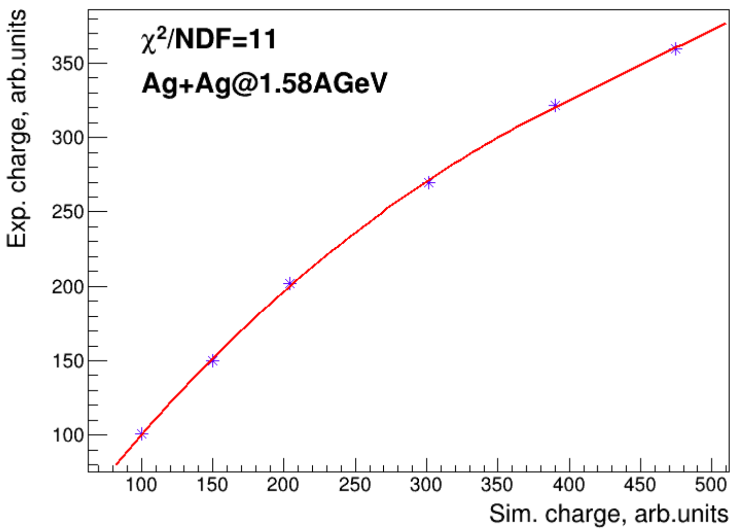


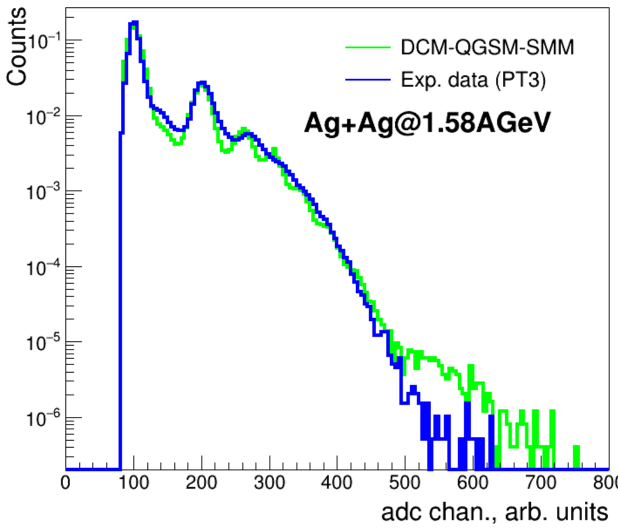


Parameterization of simulation data

- Summarize charge for all hits in each individual cell+gaus smearing with sigma 0.12
- Apply a formula : $q = \sqrt{q_{raw}} \times k$,

  where k is the coefficient that allows setting the peak position for particles with charge 1 into channel 100
- Extract mean position of each peak in experimental data and simulation, fit this dependence with the proposed functions
- Use the found parameters for functions and make parametrization





PHQMD generator for FWall - I

Clusters recognition:

- SACA (Simulated Annealing Clusterization Algorithm)
- MST (Minimum Spanning Tree)

The MST algorithm searches for accumulations of particles in coordinate space:

1. Two particles are 'bound' if their distance in the cluster rest frame fulfills

$$| r_i - r_j | \leq 4 \text{ fm}$$

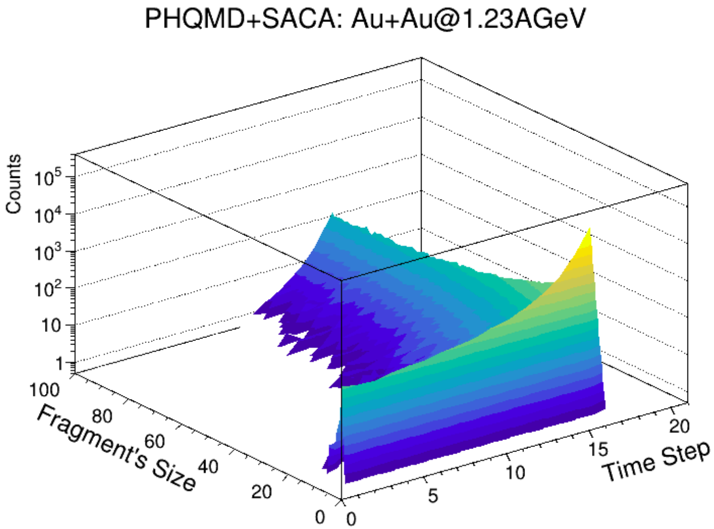
2. Particle is bound to a cluster if it bounds with at least one particle of the cluster.

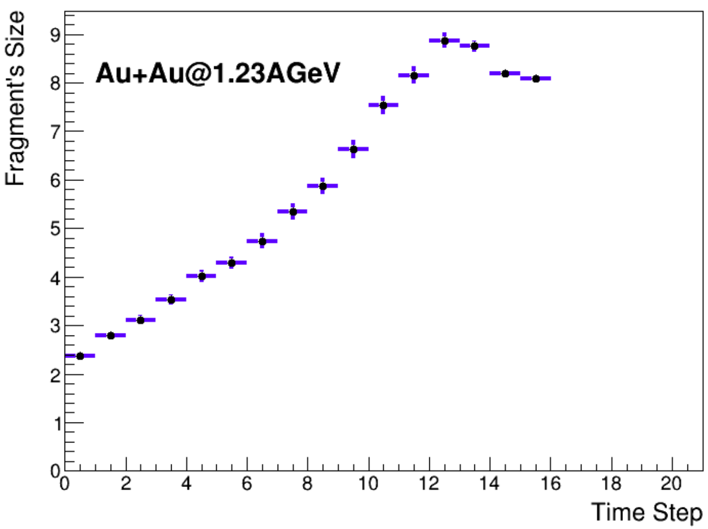
- SACA algorithm is based on the search for nucleon configurations with a minimal binding energy: SACA takes randomly one nucleon and adds it to another fragmet until the most bound configuration will be found. In SACA algorithm is it necessary to chose the time for its starting.

J. Aichelin et al., PRC 101 (2020) 044905

PHQMD generator for FWall - I

- It is the first attempt to use the PHQMD generator for the HADES experiment.
- To use the SACA fragmentation module, the fragmentation parameters were investigated depending on different predetermined times for the start of cluster formation.
- The first start time was set as 50 fm (time step 1), the final time step corresponds to 200 fm (time step 15), the step is 10 fm.

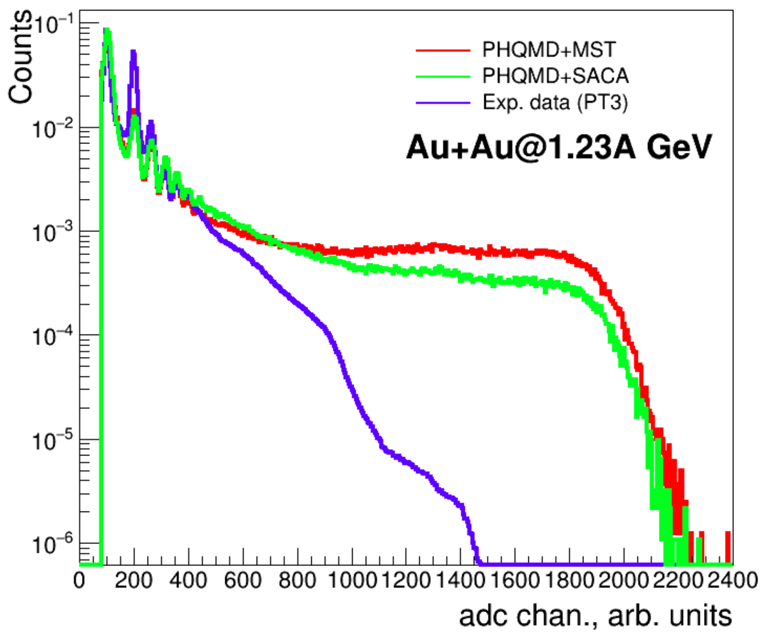




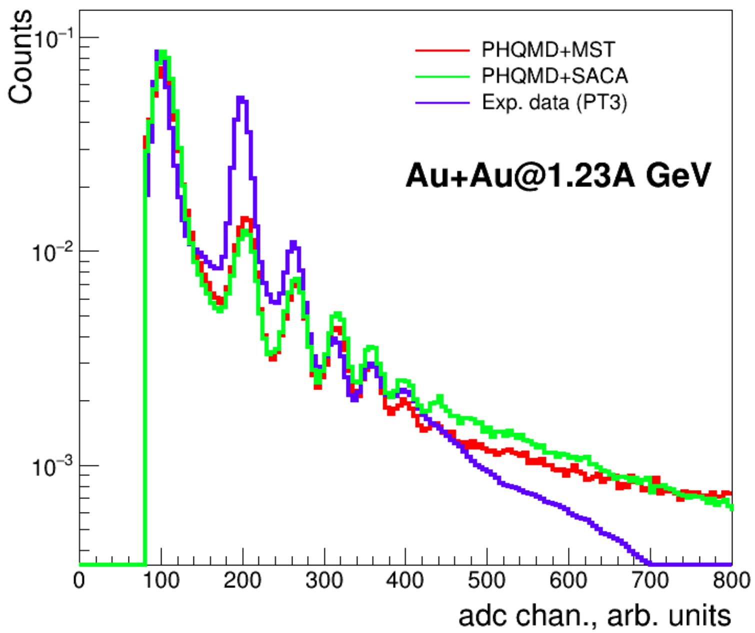
If make the algorithm start too early it will be a huge amount of clusters, if start too late after stabilisation of particles multiplicity, it will be a very few fragments.

First results with PHQMD model for FWall data

Small cells (Angle: 0.33 - 1.96°)



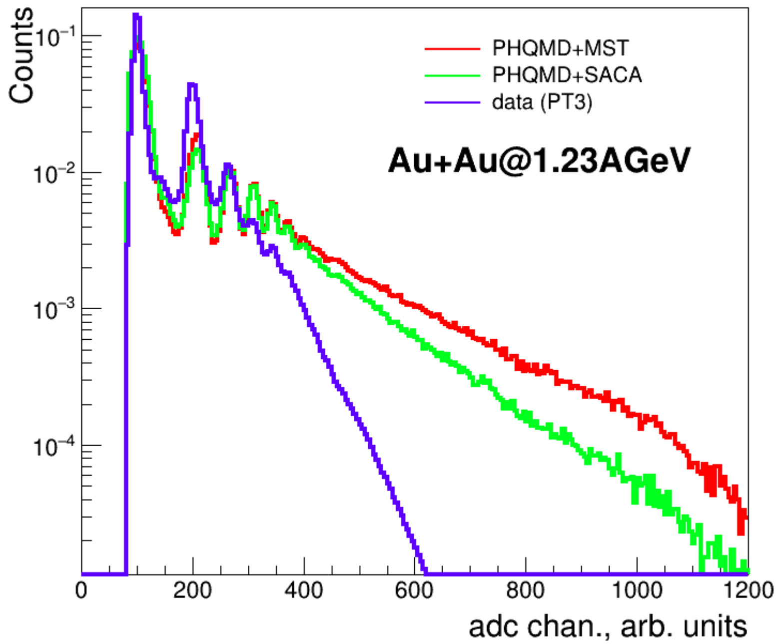
Zoom view:



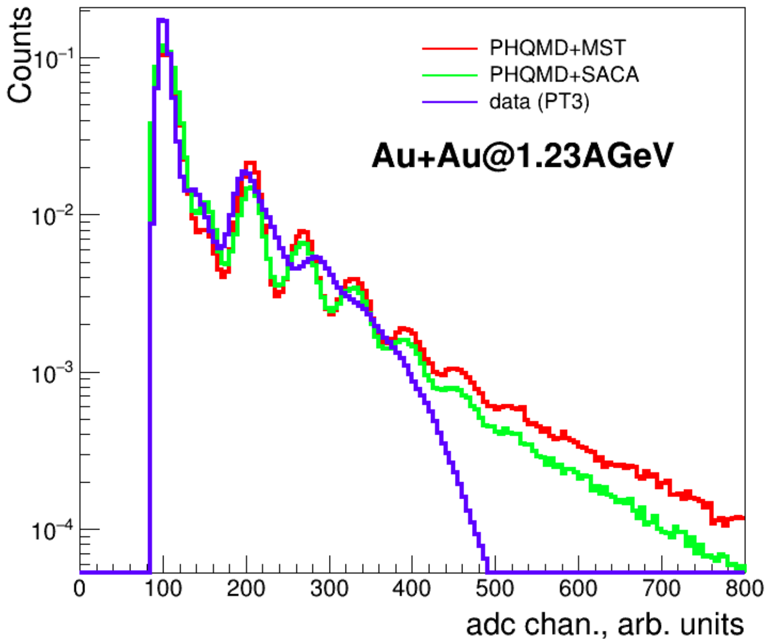
Significant divergency between experimental data and PHQMD for both fragmention modules

First results with PHQMD model for FWall data

Medium cells (Angle: 1.96 - 3.27°)



Large cells (Angle: 3.27 - 7.27°)

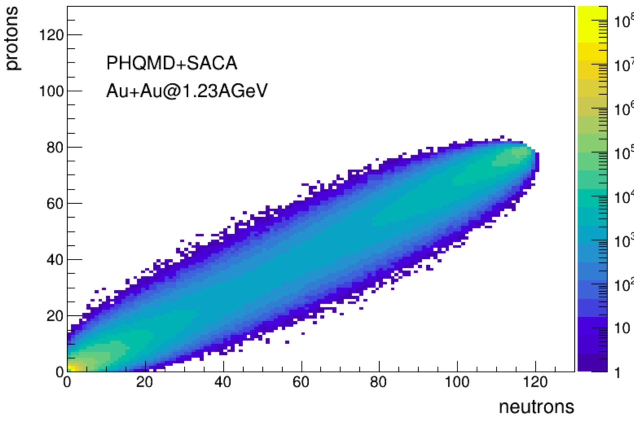


- Parametrization of the simulated data should be corrected for PHQMD model?
- Too many fragments in simulations

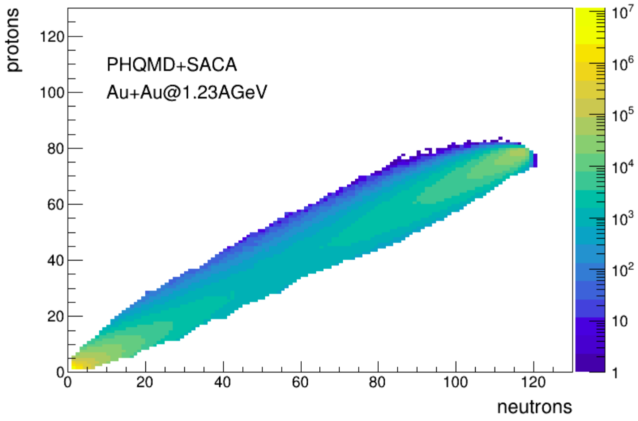
PHQMD generator for FWall - II

- A first comparison of the experimental data with a model shows that there is a significant discripancy
- During further investigations of the cluster formation in PHQMD generator it was found that there are non-existing fragments in nature
- It was developed a procedure to take into account only physical clusters

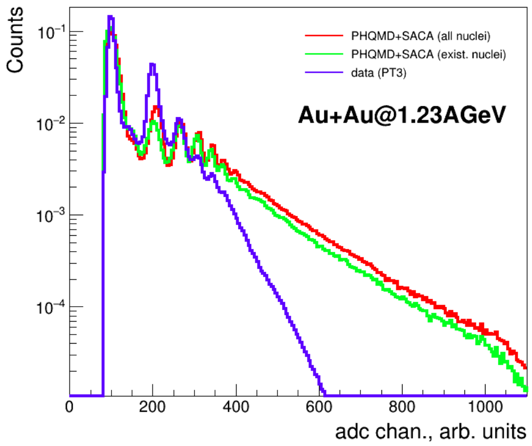
All fragments:



Physical fragments:



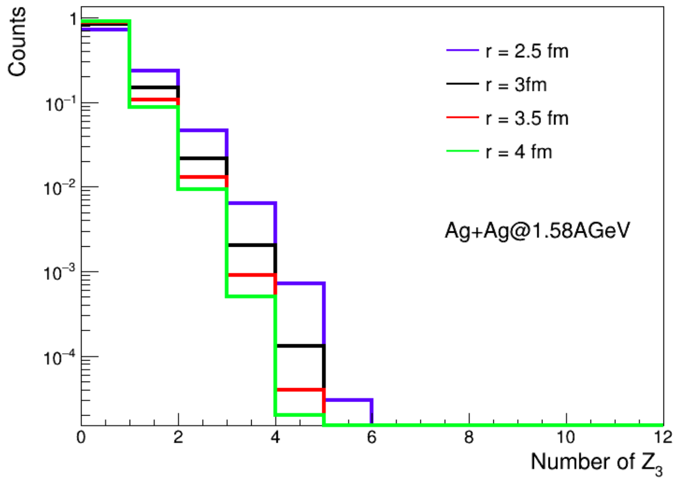
Charge comparison for medium cells



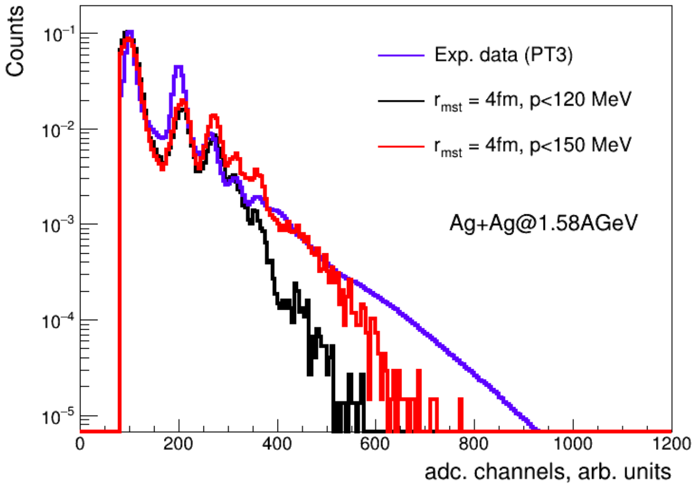
Clusterization for SMASH generator

- SMASH generator can be used as an input for make clusters from protons and neutrons
- There are 2 ways to form the clusters:
  - MST approach (only MST radii needed) and MST approach+momentum cuts
- It was developed a module for both of these approaches and were applied for Ag+Ag collisions at 1.58 AGeV and Au+Au@1.23AGeV

Number of particles with Z=3 for different MST radii



Charge in FW small cells with SMASH+MST+momentum cuts



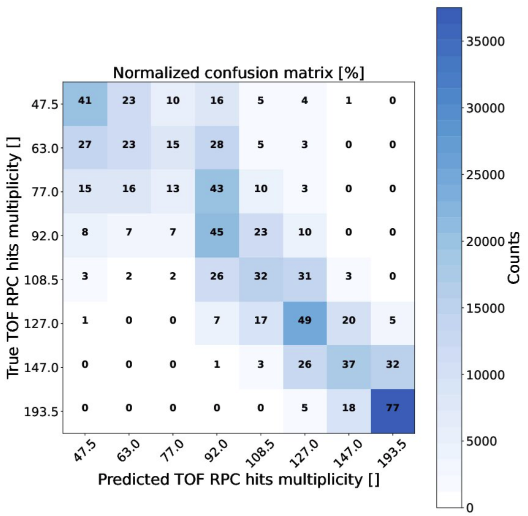
Clusterization for SMASH generator

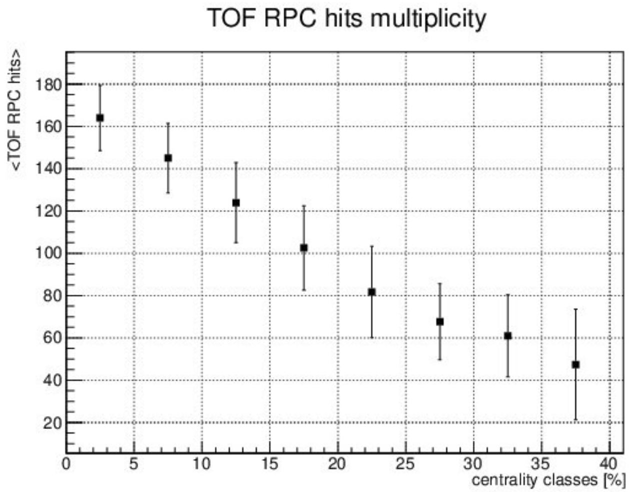
- It was found that SMASH+clusterization with parameters: r=4fm and p<120 MeV can be used for investigation of light nuclei except particles with Z=2
- Decreasing of radii increase the yields for light particles, decrease the heavier
  - In PHQMD model it is not possible to change MST radii to form the fragments, which is used for SACA module.
- Suggested clusterization doesn‘t provide a good description of heavy fragments

Centrality determination - I

- Centrality determination was done with machine learning approach
- Data was used after selection of the non-carbon events
- Training of the ML model was done based on the TOF+RPC multiplicity and corresponding mean charge values in different cells of the FWall: small, medium and large
- There were tested several configurations for FWall: different space geometry, various cuts
- After that the trained model was applied to the rest of the dataset

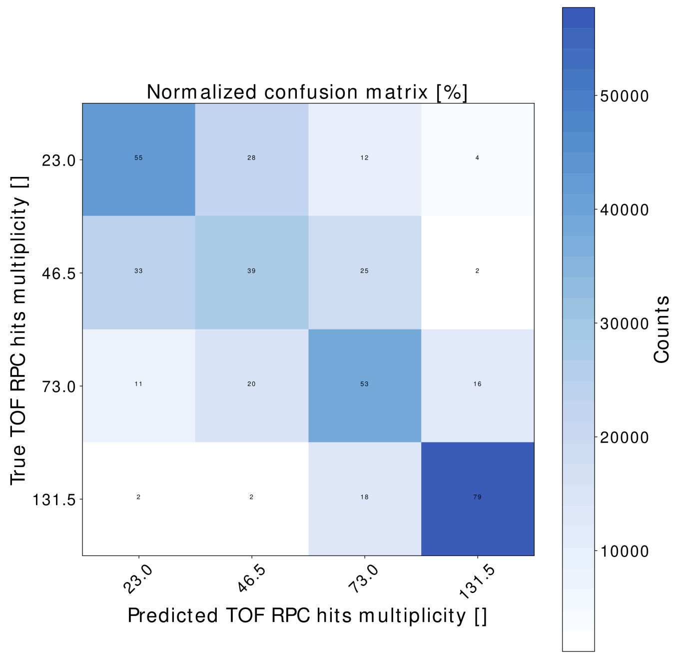
Au+Au@1.23AGeV

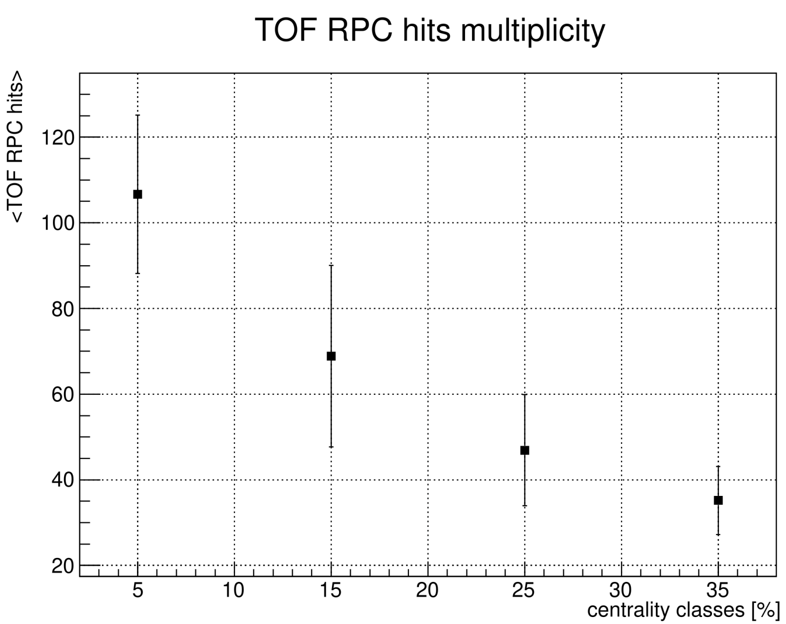




Centrality determination - II

- For Ag+Ag collisions were used the standard experimental data without any additional selection of carbon events
- Due to this reason centrality selection was performed for centrality 0-40% with a classes width of 10%.





Conclusion

- The procedure for parametrization of the modeling data was developed and applied to simulation for different collision systems
- Comparison of the FWall charge distributions was carried out for cells of different sizes between experimental data and various models
- The presented models deviate from the data for nuclei with charge Z>3
- PHQMD model was the first time used for HADES experiment
  - It was developed a procedure to exclude non-physical fragments
- It was developed a method for centrality selection with FWall detector with ML approach
- This approach was performed for Ag+Ag@1.58AGeV and Au+Au@1.23AGeV collision systems

Outlook and future plans

- The proposed parametrization of the FWall modeling data can be used by HADES Collaboration in future works
- FWall can be used for carbon contamination issue in silver-silver collisions (as well as simulation with FWall)
- Generations of the PHQMD model could be futher invetigated for different HADES subsystems and analysis of light nuclei
- Currectly, centrality selection with ML can be used in the beginning of the data collection and will be improved
- SMASH+parametrization can be used for light nuclei analysis
- PHQMD generator – the decay process should be performed in accordance with real decays of the particles, should be tuned for small colliding energies

Acknowledgment

- To the DAAD Exchange Program for the opportunity to make the presented project
- Prof. Tetyana Galatyuk for informative and crucial discussions, comments, assistance throughout the project
- HADES Collaboration to provide access to experimental data, GSI computer equipment, workspace and useful discussions

Thank you for your attention

Back Up

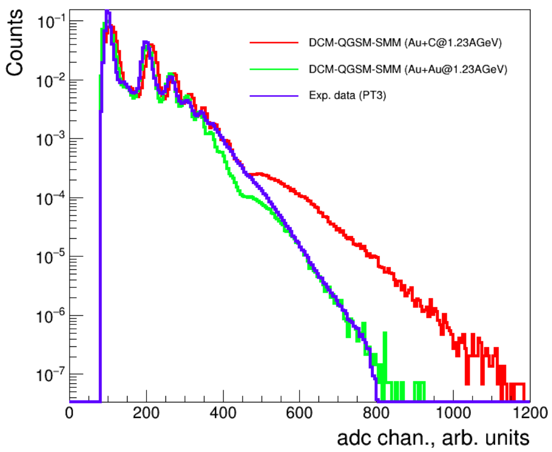
Study on the carbon contamination - I

- Modeling with DCM-QGSM-SMM and SHIELD generators A+A and A+C events for the HADES experimental setup:

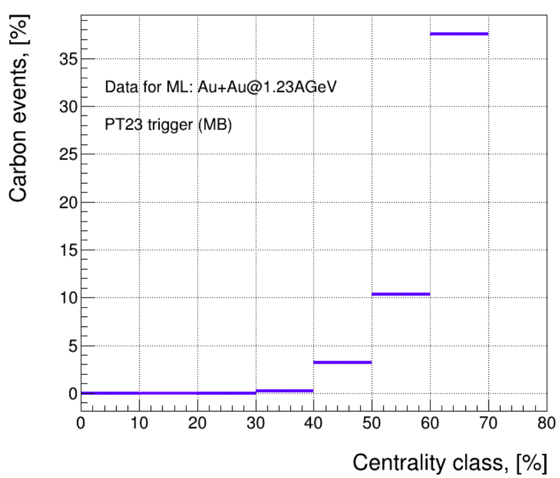
  Generator → Geant → Reconstruction → FWall Parametrization → Analysis
- Different variables were studied:
  - Charge and number of hits in FWall
  - Average transverse momentum
  - Average rapidity of particles
  - Correlations between FWall charge and TOF+RPC hits
  - Centrality dependencies
- Various approaches were used:
  - Using exerimental data in target and START detector regions
  - Mixing A+A and A+C events in simulations
  - Comparison of the A+A and A+C simulations
  - Machine learning made by Mateusz W. (produced particles)
  - Test of the machine learning with FWall

Study on the carbon contamination - I

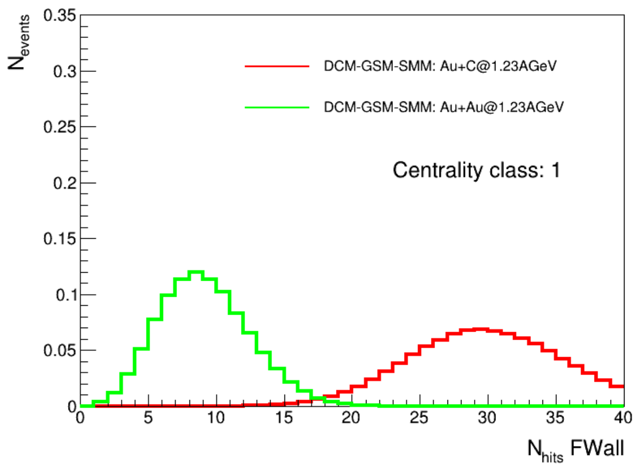
Charge of the medium cells:

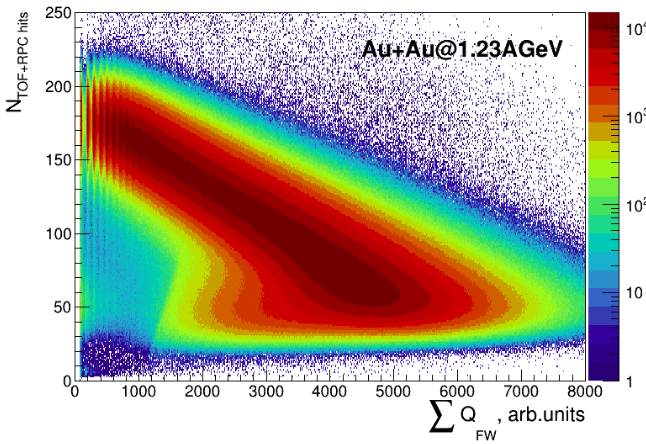


Carbon events recognized by ML for PT23 trigger



FWall hits in centrality 0-10%:





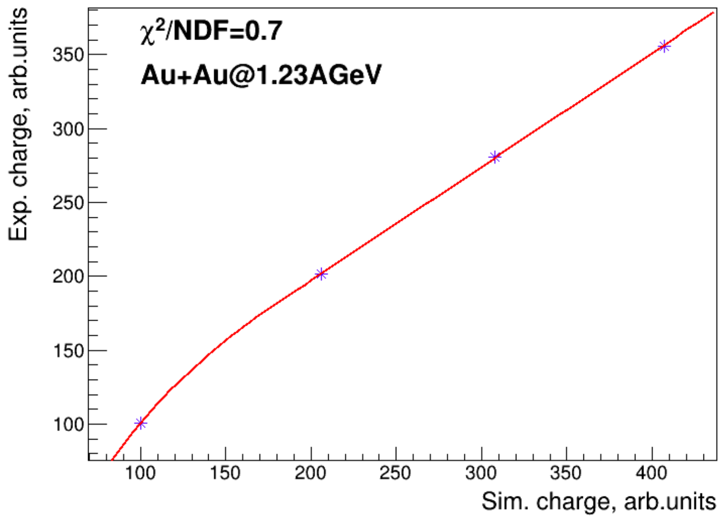
Study on the carbon contamination - II

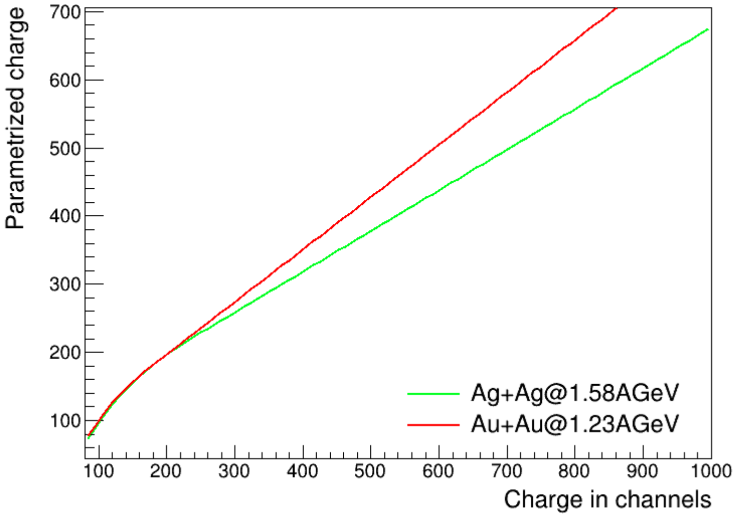
Results of studying carbon contamination with different approaches:

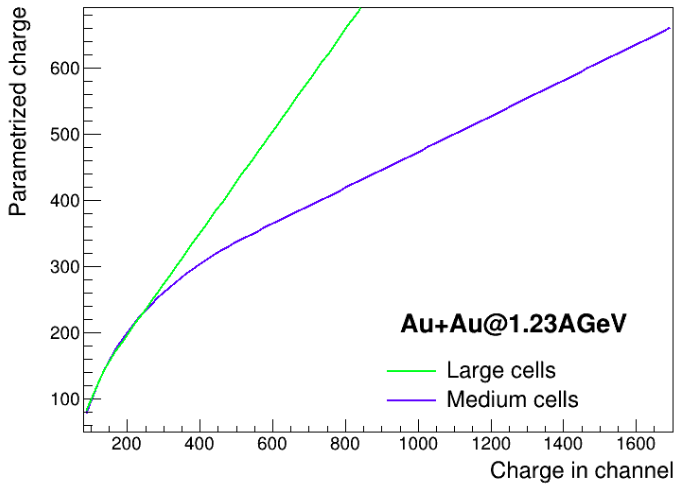
- Comparison of the FWall amplitudes shows that in A+C yields of the heavier fragments are larger than in A+A collisions
- FWall hits and charge are sensitive to the colliding system in various centrality classes and can be used as an additional variable for this study
- Central trigger (PT3) provide a precise physical information almost without carbon contribution for gold-gold collisions
- Applying ML for carbon contamination does not solve discrepancy problem between FWall experimental data and model

Parametrization of the FWall amplitude for different colliding systems

Large cells:



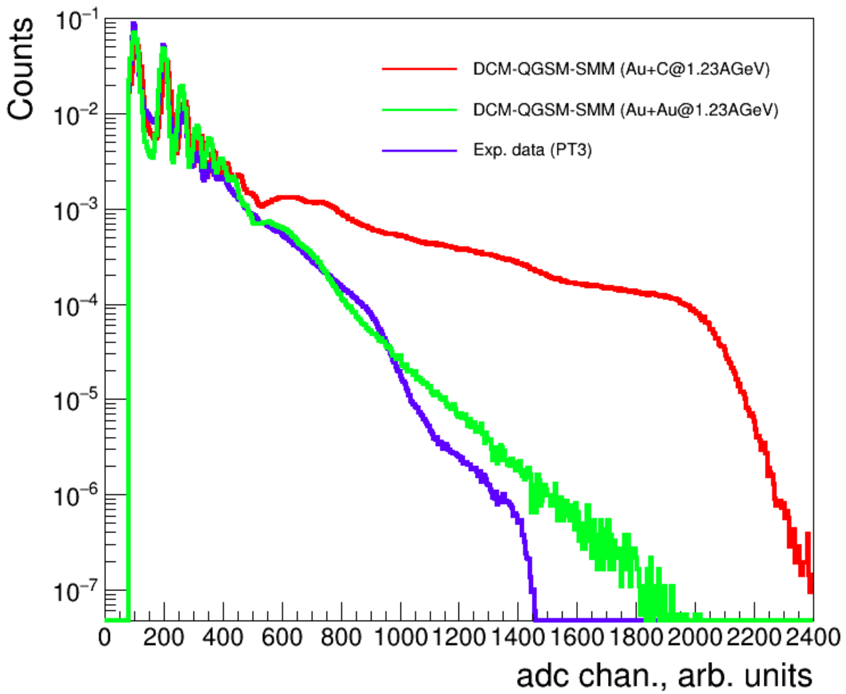




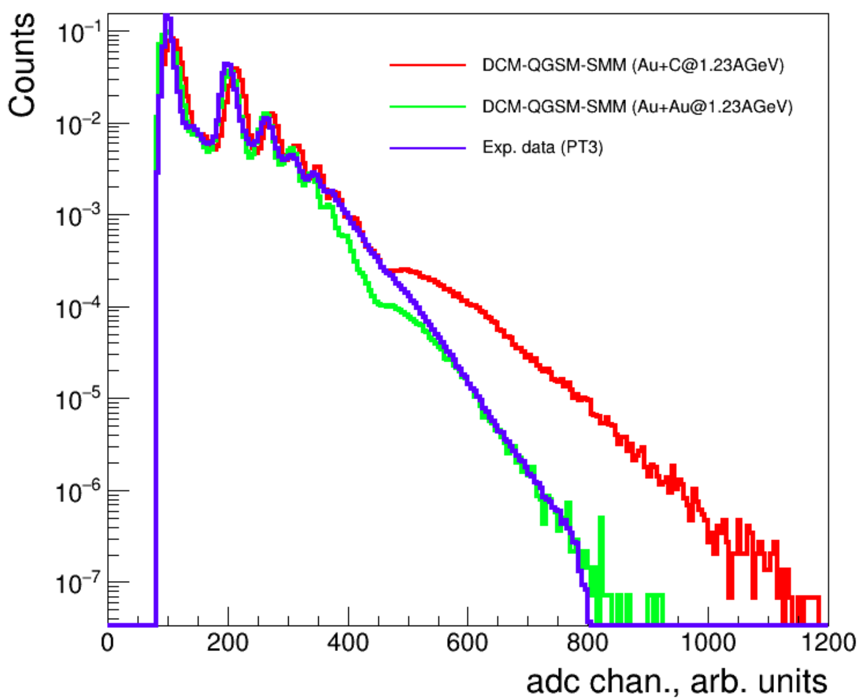
Large & Medium cells

FWall amplitude in Ag+Ag and Ag+C reactions

Small cells:

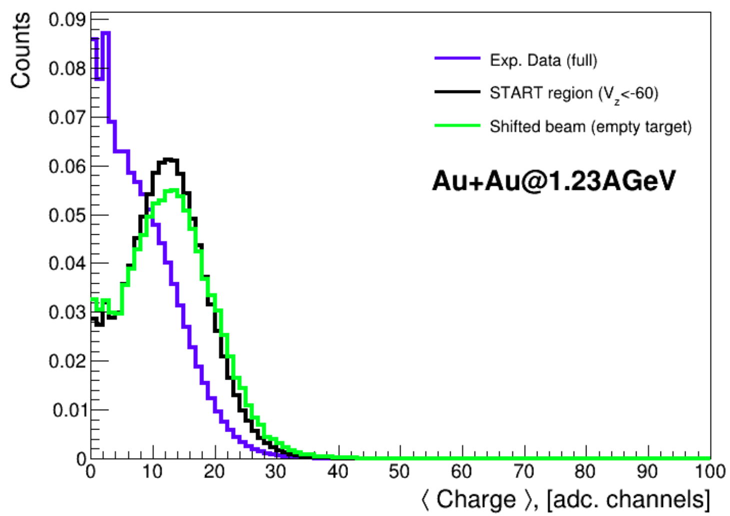


Medium cells:

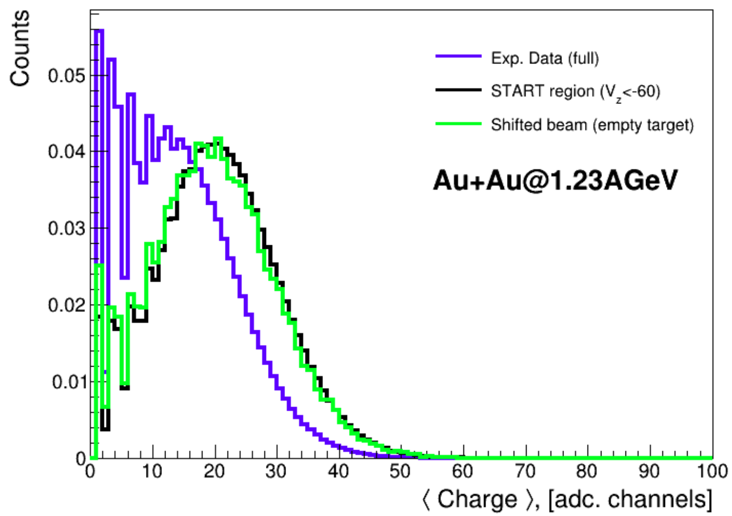


FWall amplitude in V_z (START vs Target)

Small cells



Medium cells



CNN model

In this work for centrality determination is used CNN (Convolution Neural Network).

- The first two layers with 32 filters of window size 10×10 and 3 × 3 correspondingly. The output will have 32 feature maps.
- The input layer of the model contains image of FWall experimental charge in each cells in accordance with their positions. The image data has dimension 33 × 33.
- The second layers of the model is Max Pooling of size (2 × 2), which reduce the dimensions of feature map.
- Then it is used the DropOut to avoid overfitting, the dropout rate is 0.2
- Fully connected layer involves weights, biases, and neurons. It connects neurons in one layer to neurons in another layer. It is used to classify images between 8 categories. Output layer contains labels