The Influence of the Ion Beam Pipe on the Accuracy of Determining the Coordinates of Interaction Points in Ion-Ion Collisions at the NICA Collider.

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Objective of the Research

The goal of the research was to develop an algorithm for determining the initial collision coordinate of Au-Au nuclei at an energy of $\sqrt{s_{NN}} = 7$ GeV based on data obtained from microchannel plate detectors. To achieve this goal, the following tasks were solved:

- Improvement of a neural network algorithm for determining the collision coordinates of ion nuclei;
- Using this algorithm to evaluate the influence of various configurations and materials of the NICA collider's ion beam pipe on the accuracy of determining these coordinates.

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Software Packages Used For Modeling

- The chromo interface for the UrQMD 3.4 event generator was used for simulating interactions.
- Data obtained on previous step were imported into a program implemented using Geant4.
- This program was used to simulate particle propagation from the interaction point to the detecting devices, taking into account the influence of various ion beam pipe configurations.

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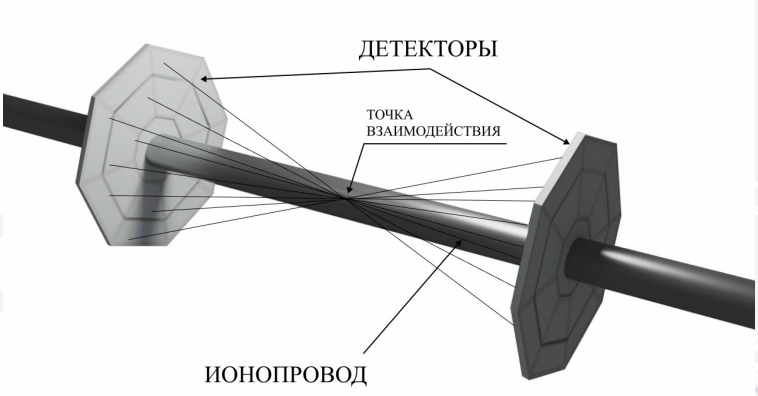
Ion Beam Pipe Configuration

The following wall thicknesses d of the ion beam pipe were considered: 0, 1.2, 3, 5, and 8 mm, with materials being carbon and iron. Two detector configurations were used: with 32 pads (segments) and 64 pads.



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Algorithm

- Our research is based on the study Sandul, V. S., Feofilov, G. A., Valiev, F. F. (2023). "Studying Capabilities of a Fast Monitor for Beam Collisions by Monte Carlo Simulations and Machine Learning Methods. Phys. of Particles and Nuclei 54(4), 712-716.
- This study used machine learning algorithms to improve the accuracy of solving the initial coordinate problem.
- It has been found that a fully connected neural network gives more accurate results compared to the gradient boosting algorithm on decision trees.
- Therefore, we tried to improve the neural network approach.

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Algorithm

The detector system configuration considered in this research allows the determination of the following parameters for registered particles:

- The coordinate of the registered particle;
- The particle's time-of-flight;
- The localization parameter on the detector (pad number).

An approach using these parameters as input data was improved. The root-mean-square error (RMSE) was chosen as the accuracy metric.

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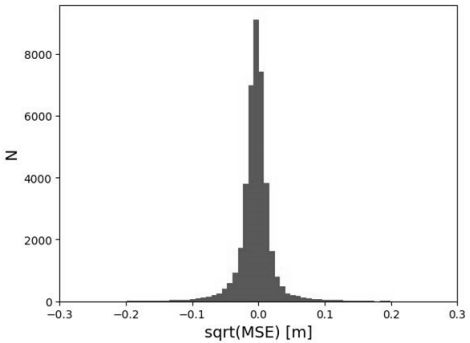
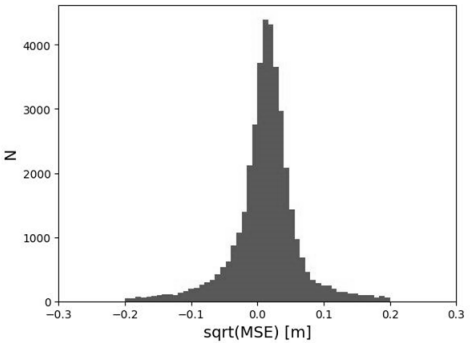
Comparison of Fully Connected and Convolutional Neural Networks



(a) Convolutional neural network. $\sqrt{MSE} = 3.14$ cm.



(b) Fully connected neural network. $\sqrt{MSE} = 5.31$ cm.

The influence of the ion beam pipe is not taken into account.

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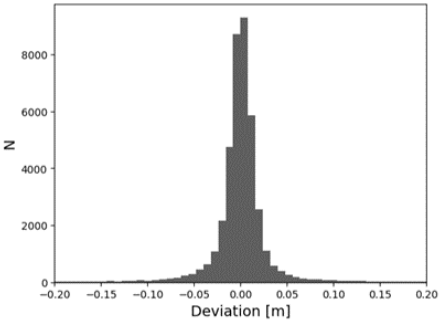
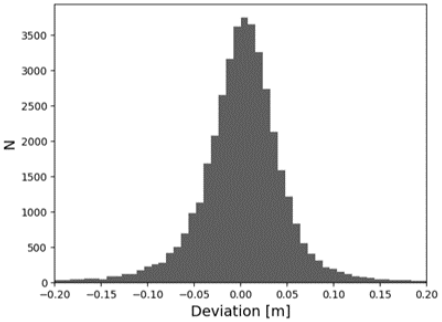
Evaluation of Ion Beam Pipe Influence



(a) Ion beam pipe influence not considered. $\sqrt{MSE} = 3.62$ cm.



(b) Ion beam pipe wall thickness - 8 mm, material - iron. $\sqrt{MSE} = 5.27$ cm.

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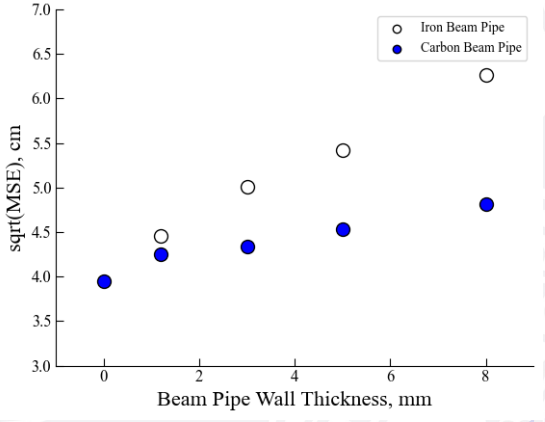
Detector with 32 Pads: Coordinate Determination Error

Dependence of the error on the material and wall thickness of the ion beam pipe. Time resolution of 200 ps.



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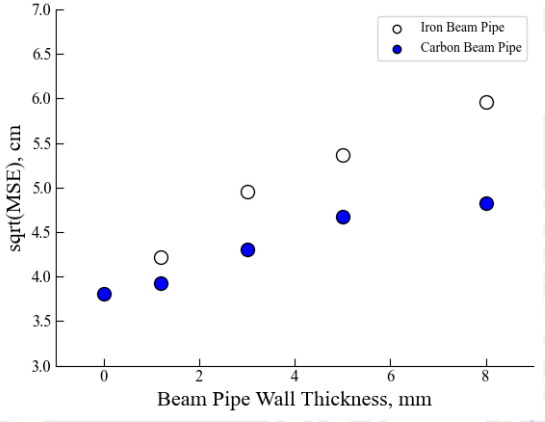
Detector with 64 Pads: Coordinate Determination Error

Dependence of the error on the material and wall thickness of the ion beam pipe. Time resolution of 200 ps.



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Coordinate Determination Error

The best results with realistic time resolution were obtained for the 64-pad configuration. Dependence of the $\sqrt{MSE}$ error in determining initial coordinates and its average deviation $\Delta\sqrt{MSE}$ on the material and wall thickness of the ion beam pipe. Time resolution of 200 ps, 64 pads.

Material	Iron		Carbon	
Thickness, mm	$\sqrt{MSE}$, cm	ΔMSE, cm	$\sqrt{MSE}$, cm	ΔMSE, cm
0	3.81	0.22	3.81	0.22
1.2	4.23	0.21	3.93	0.19
3	4.95	0.28	4.30	0.22
5	5.22	0.26	4.68	0.23
8	5.96	0.30	4.82	0.32

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Conclusions

- The neural network approach using a convolutional network allows for the required accuracy in reconstructing the initial corrdinate of Au-Au interactions at the planned NICA collider energy of $\sqrt{s_{NN}} = 7$ GeV.
- An ion beam pipe with wall thicknesses of 1-3 mm has a negligible effect on accuracy.
- Increasing the ion beam pipe thickness to 8 mm degrades accuracy by a factor of 1.2-1.4 depending on the material.
- The effectiveness of the proposed approach for evaluating the influence of detector components on the accuracy of nuclear interaction coordinate determination has been demonstrated, which is important for the design of NICA collider detectors.

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Thank you for your attention!

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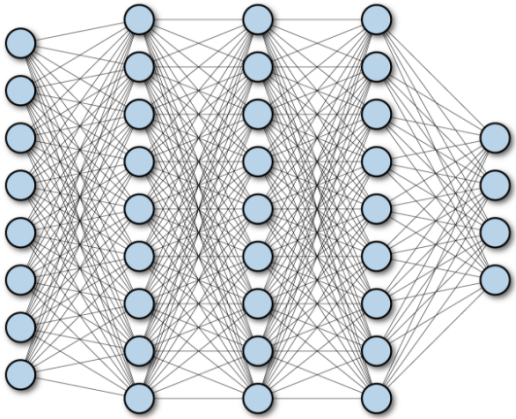
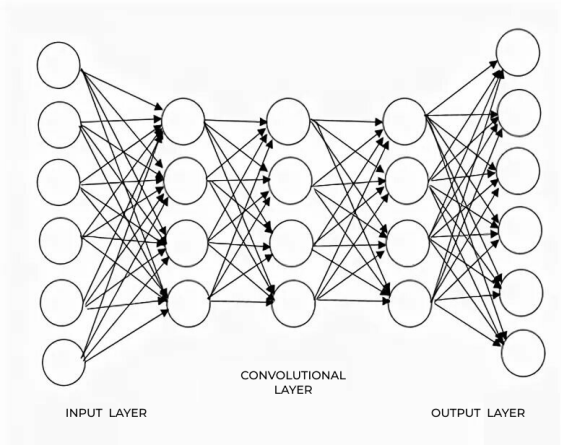
Appendix: Fully Connected Neural Network



Appendix: Convolutional Neural Network (CNN)



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Appendix: Fully Connected Neural Network

Working Principle

- All neurons in adjacent layers are pairwise connected
- Each connection has a unique weight

Key Properties

- Universal "black box"for any data
- Requires significant computational resources

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Appendix: Convolutional Neural Network (CNN)

Working Principle

- Uses local receptive fields (convolution kernels)
- Kernel weights are shared across the entire feature map
- Preserves spatial data structure

Key Properties

- Specialized for images/video/audio
- Saves parameters through weight sharing
- Automatically extracts feature hierarchies

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