Neural network domain adaptation for addressing the generator-dependence problem in impact parameter estimation

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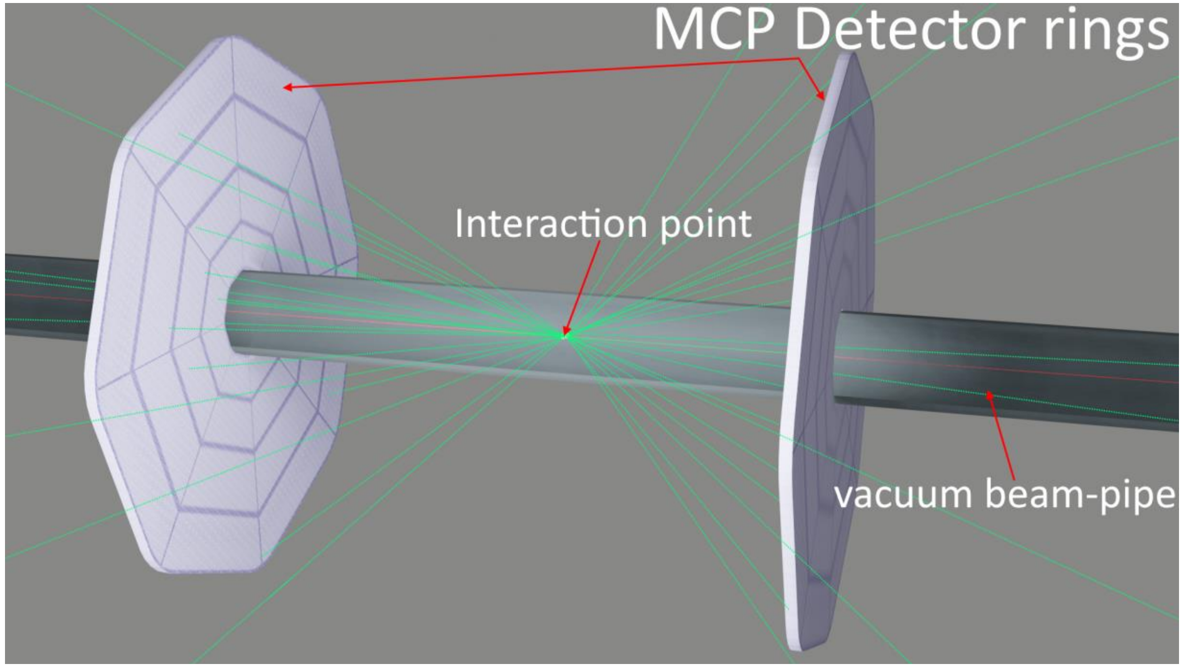
The problems of event parameters estimation

Studied problems

- Estimate the value of the impact parameter
- Select head-on collisions (small impact parameter)



Scheme of investigated detectors geometry

We used MC generated data of Au+Au collisions at energies $\sqrt{s_{NN}} \approx 11$ GeV, which consists of three datasets:

- 200 000 events generated by **QGSM[1]** model
- 360 000 events generated by **EPOS[2]** model
- 50 000 events generated by **PHQMD[3]** model

Hits information that was used for feature engineering:

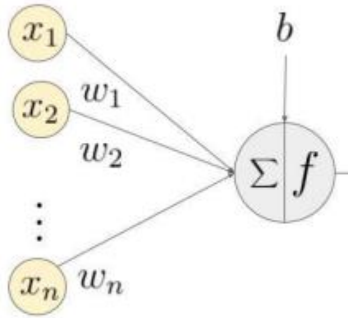
- Which cell registered hit
- Number of detector ring
- Particle time of flight

[1] Amelin N. S., Gudima K. K., Toneev V. D. Ultrarelativistic nucleus-nucleus collisions within a dynamical model of independent quark - gluon strings // Sov. J. Nucl. Phys. 1990. V. 51(6), P. 1730-1743

[2] Werner, Klaus and Liu, Fu-Ming and Pierog, Tanguy Parton ladder splitting and the rapidity dependence of transverse momentum spectra in deuteron-gold collisions at the BNL Relativistic Heavy Ion Collider
// Physical Review C 2006, V. 74

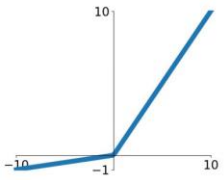
[3] Aichelin, J. and Bratkovskaya, E. and Le Fèvre, A. and Kireyeu, V. and Kolesnikov, V. and Leifels, Y. and Voronyuk, V. and Coci, G., Physical Review C 2020, V. 101

Used artificial neural networks



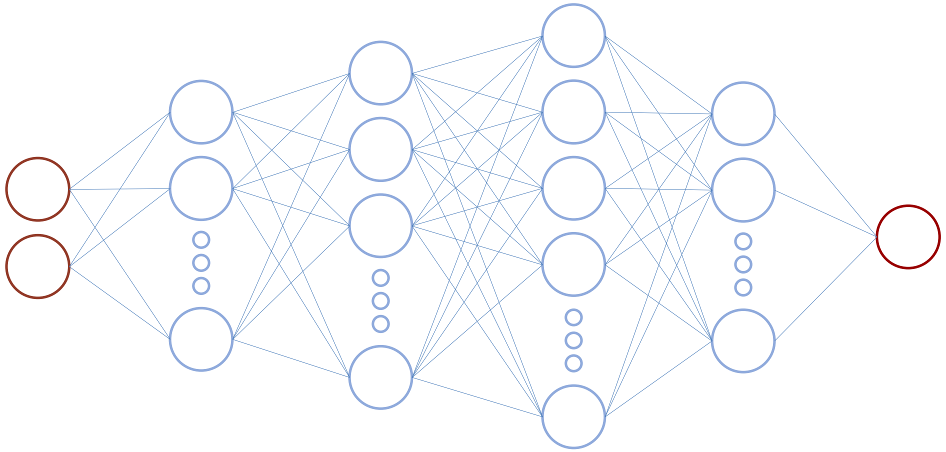
$$f\left(b+\sum_{i=1}^{n} x_i w_i\right)$$

Scheme of an artificial neuron model



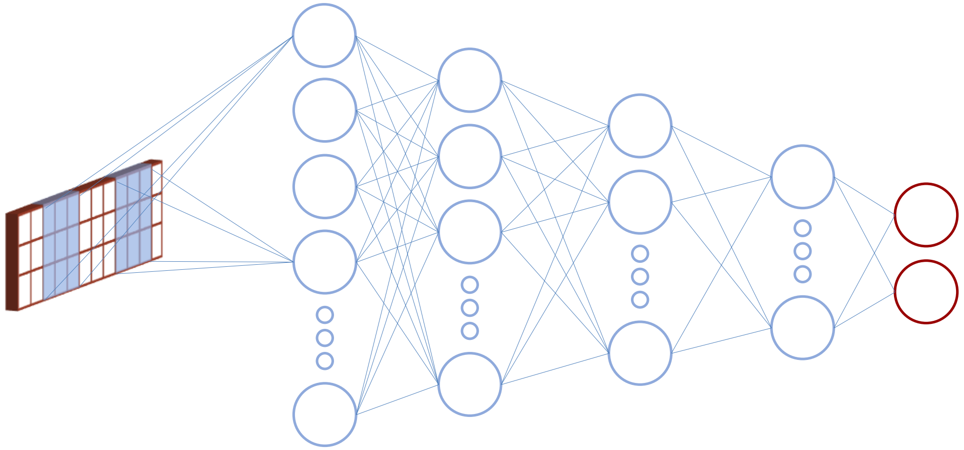
Leaky ReLU

$f(x) = \max(0.01x, x)$



Example of used dense neural network architecture, solving regression problem.

Input – 2 event features, 4 hidden layers (4, 8, 16, 4 neurons), output – 1 neuron – estimated impact parameter value



Example of used dense neural network with convolutional layer, solving classification problem.

Input – Table of particles information (3x150 features), convolutional layer (16 filters 3x6), 3 hidden layers (128, 64, 32 neurons), output – 2 neurons – probabilities of an event belonging to each class.

Leaky ReLU activation function. Optimizer – Adam. Optimized functions – mean squared error, binary cross entropy.

Multiplicity of charged particles and the average polar angle of trajectories

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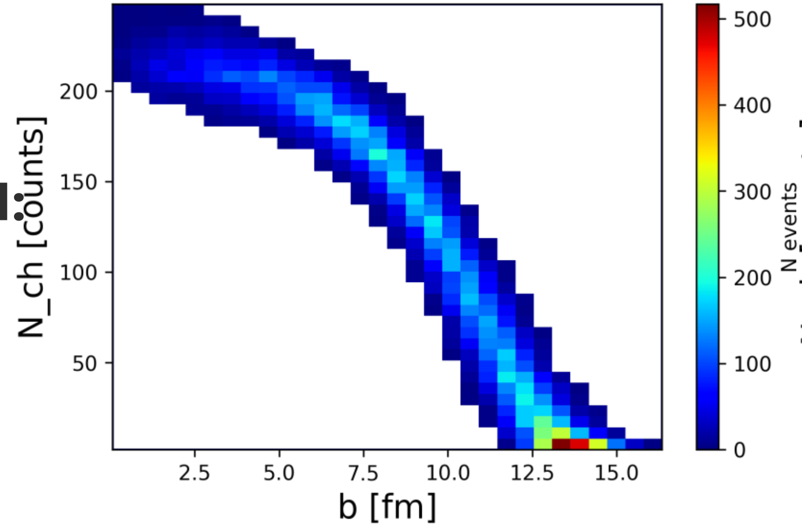
QGSM:

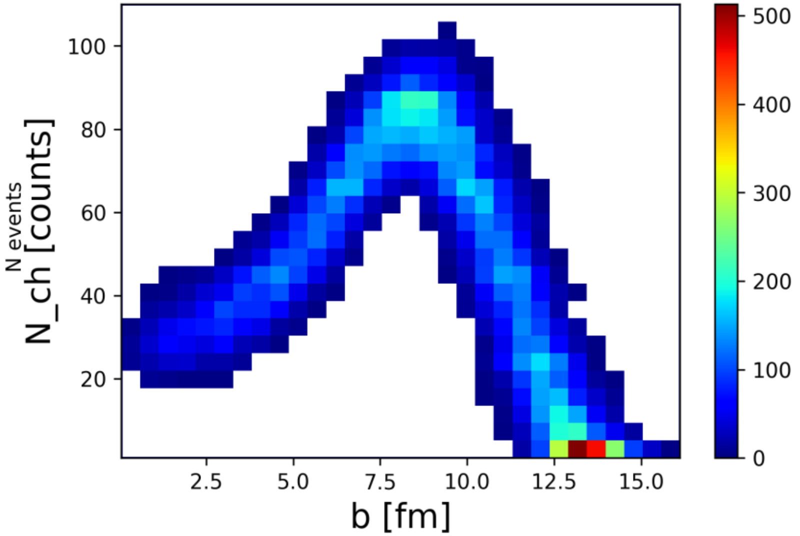
Multiplicity, R=1m

Events distribution by impact parameter and number of hits



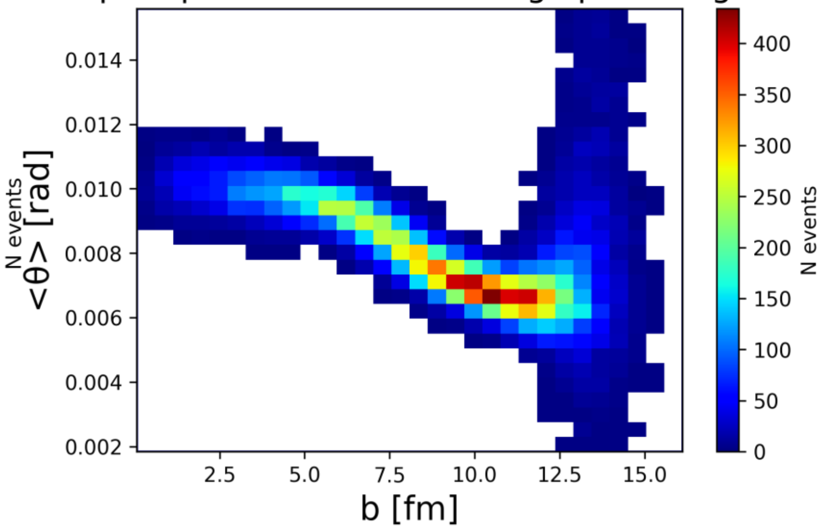
Multiplicity, R=0.25m

Events distribution by impact parameter and number of hits



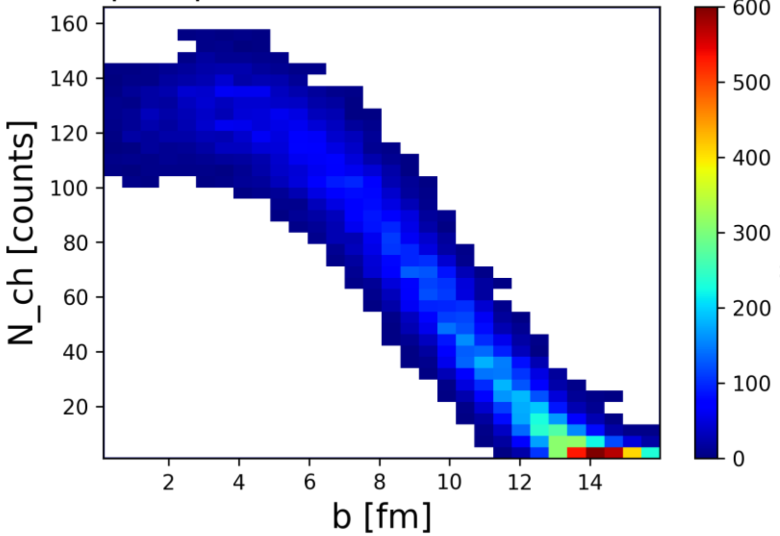
Average angle

Events distribution by impact parameter and average polar angle

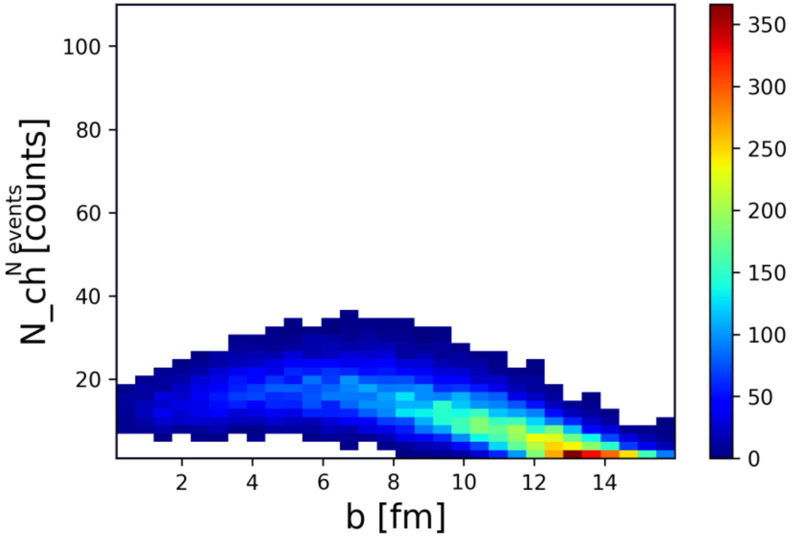


EPOS:

Events distribution by impact parameter and number of hits



Events distribution by impact parameter and number of hits



Events distribution by impact parameter and average polar angle

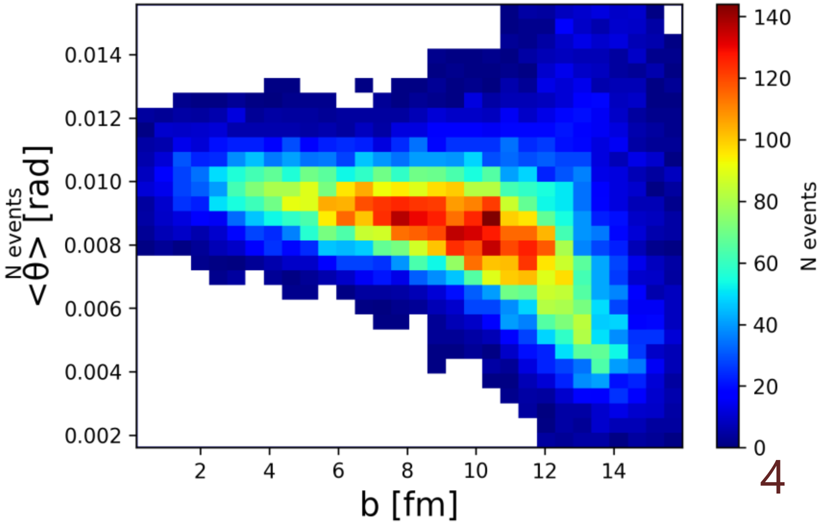


Table of NN performance

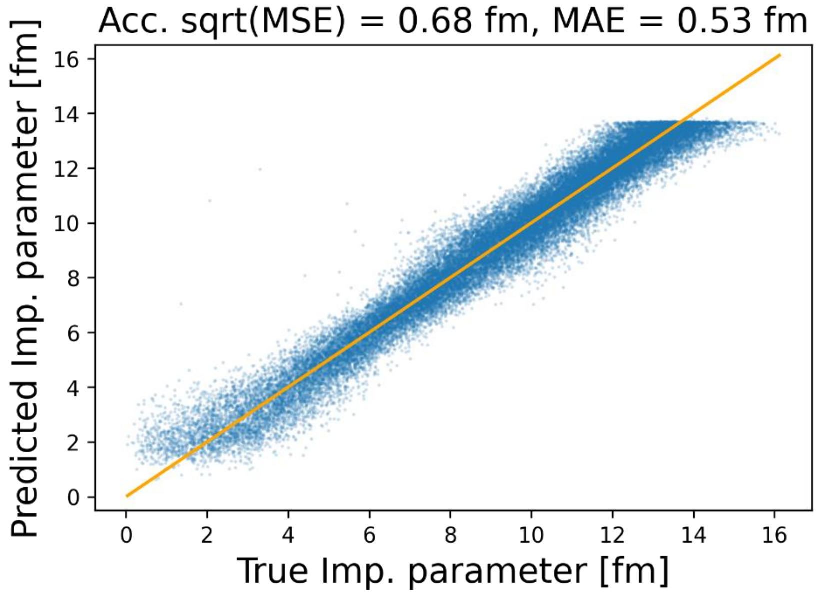
Event features (Number of features)	Binary classificatory threshold [fm]	QGSM			EPOS		
		MSE [fm]	TPR [%]	FPR [%]	MSE [fm]	TPR [%]	FPR [%]
Time of flight (3x150)	5	0,68	98,6	4,3	1,53	91,7	16,4
Time of flight (3x150)	1		90,3	6,2		94,0	17,8
Multiplicity + angle (2)	5	0,77	97,7	5,8	2,06	88,1	38,1
Multiplicity + angle (2)	1		98,9	8,8		77,2	21,1

Here we used detector system consisting of pair of rings with R=25cm, r=2.5cm, L=4m, Δt=50ps, 352 cells.

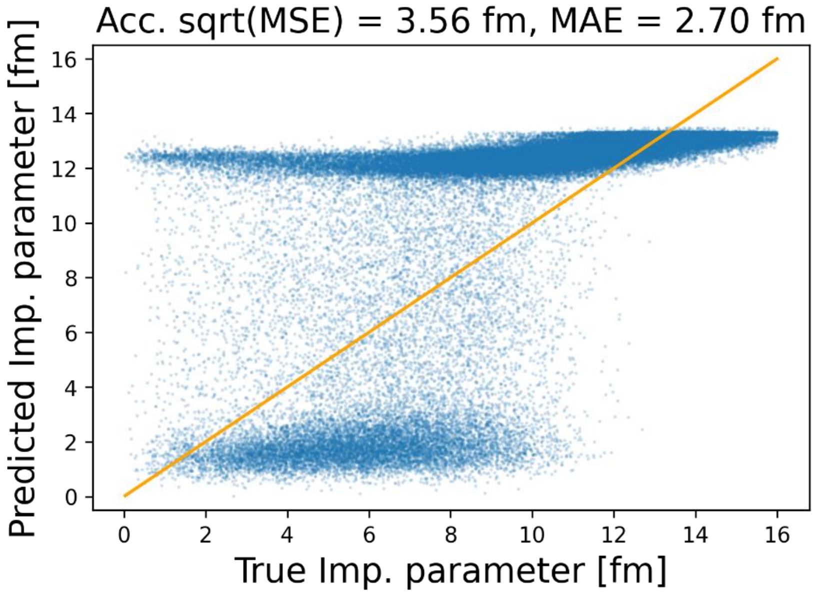
TPR – true positive rate, FPR – false positive rate.

Simple network trained on QGSM dataset

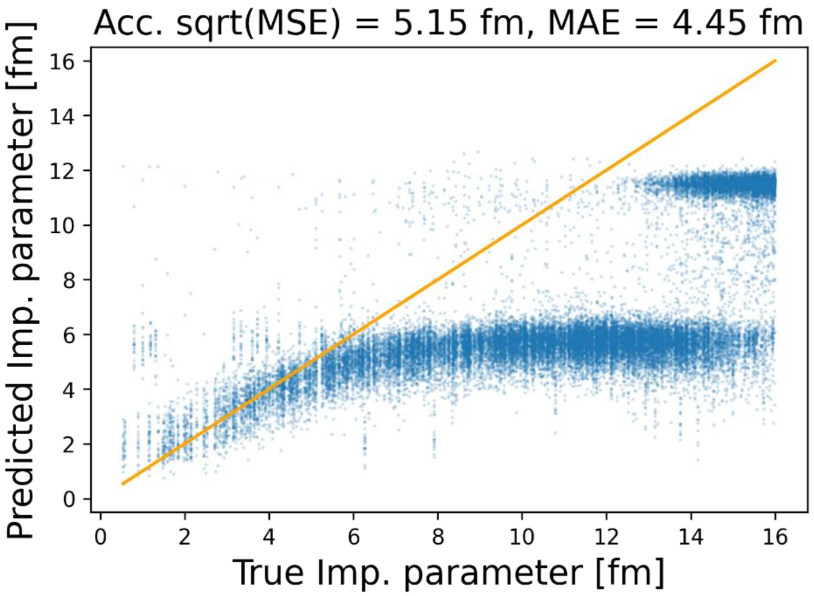
Tests on: QGSM



EPOS

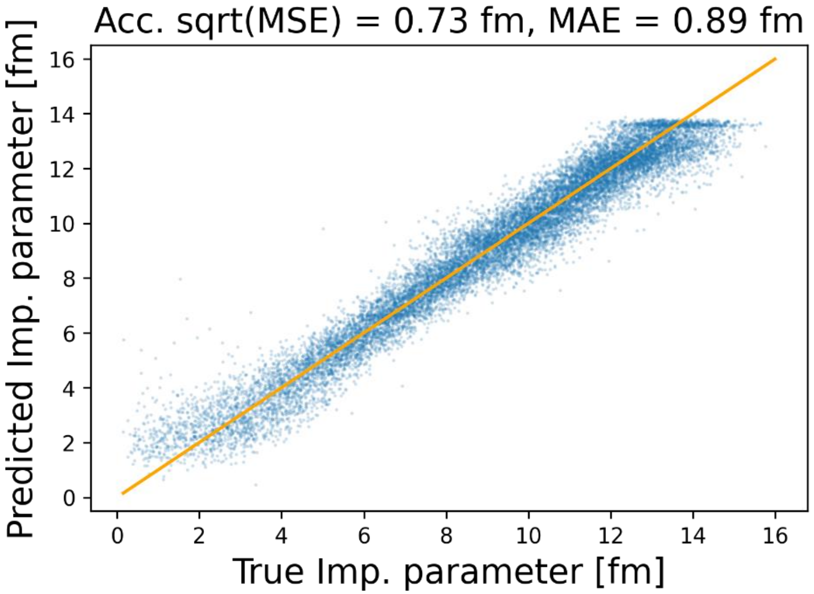


PHQMD

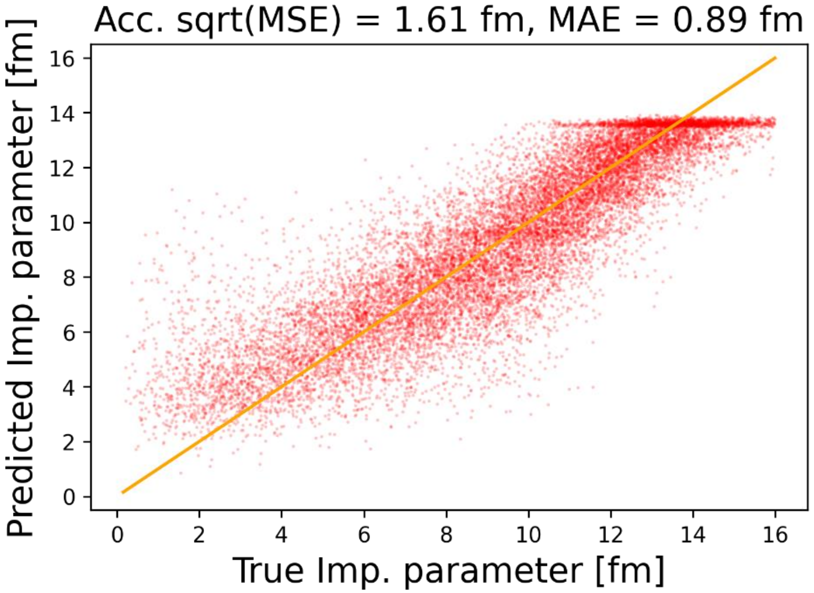


Simple network trained on QGSM+EPOS mixed dataset

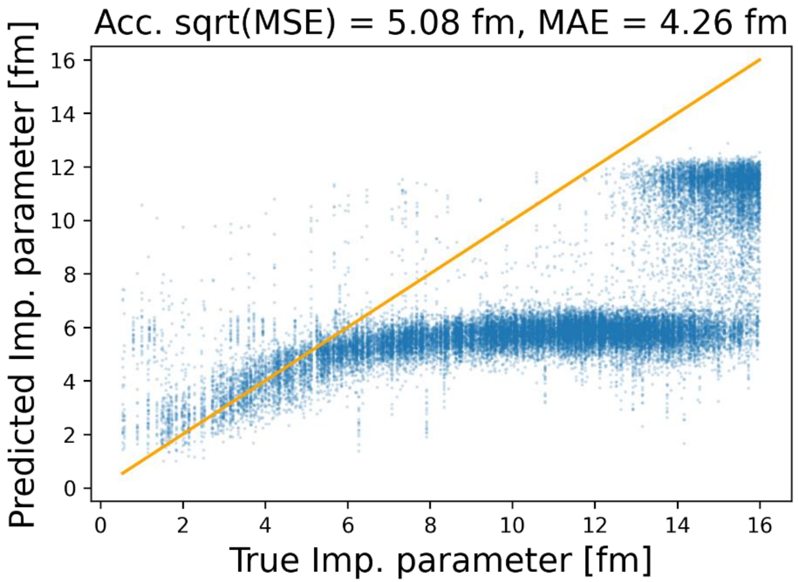
Tests on: QGSM



EPOS



PHQMD



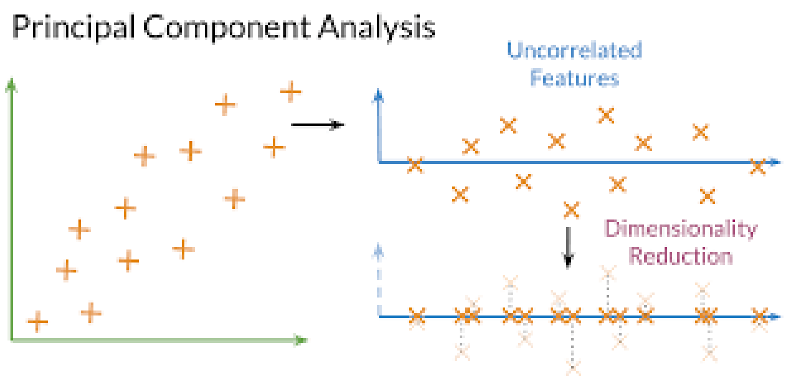
Search for universal event characteristics

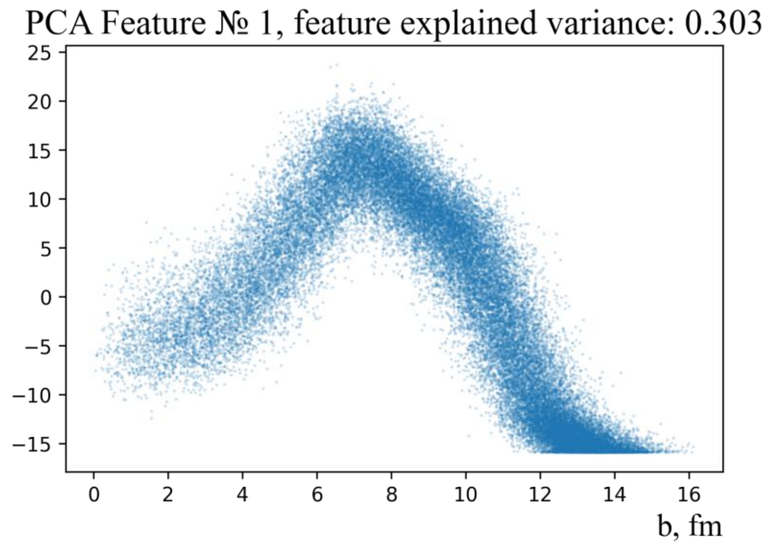
The idea of method

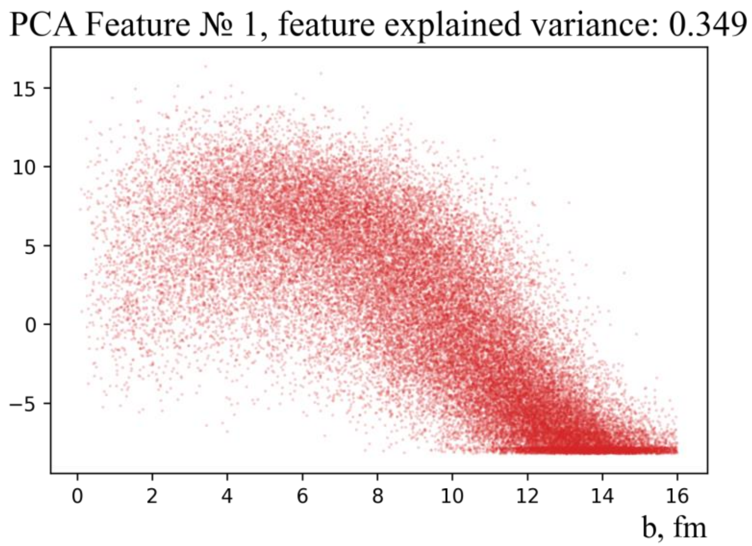
QGSM:

EPOS:

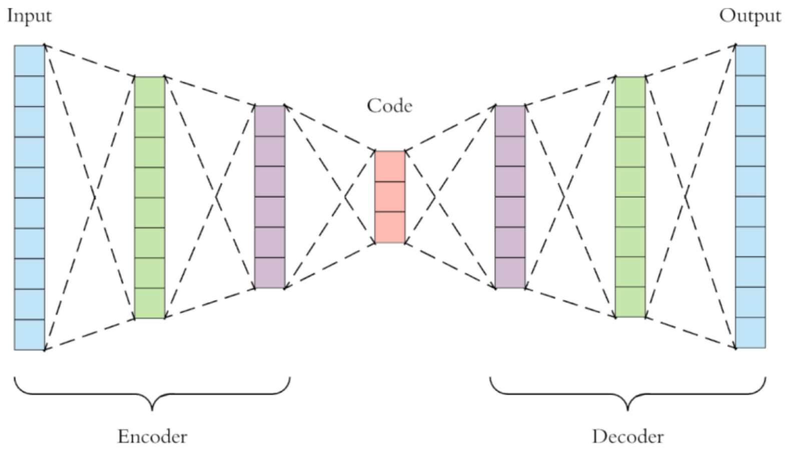
PCA:

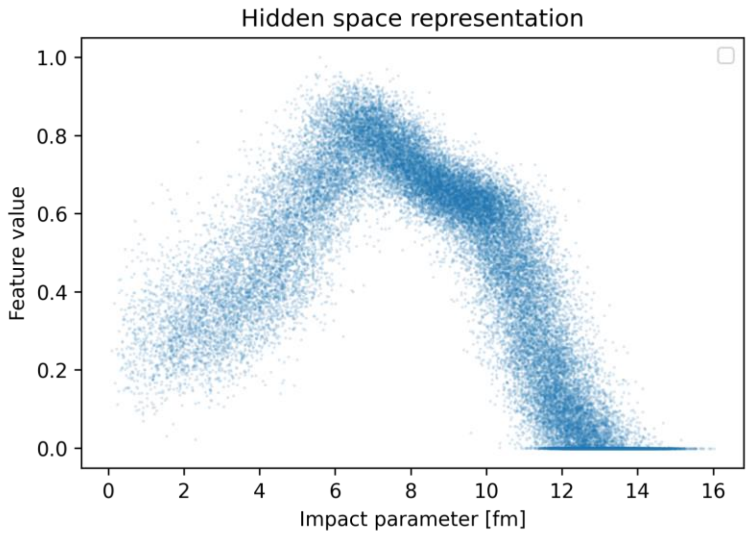


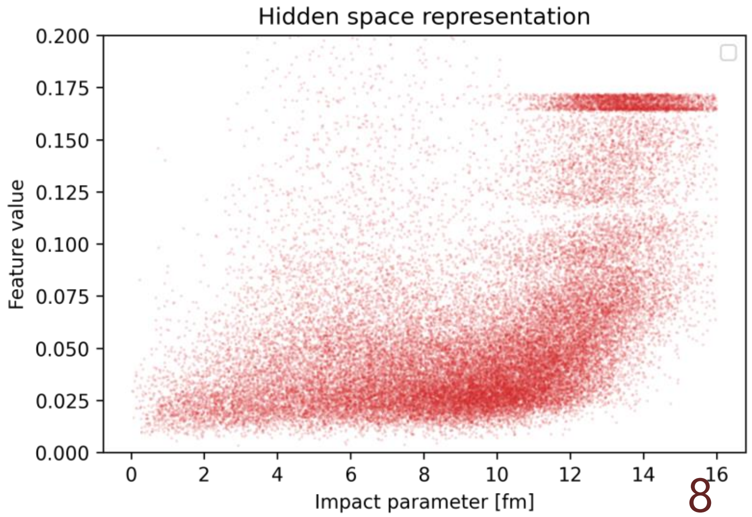




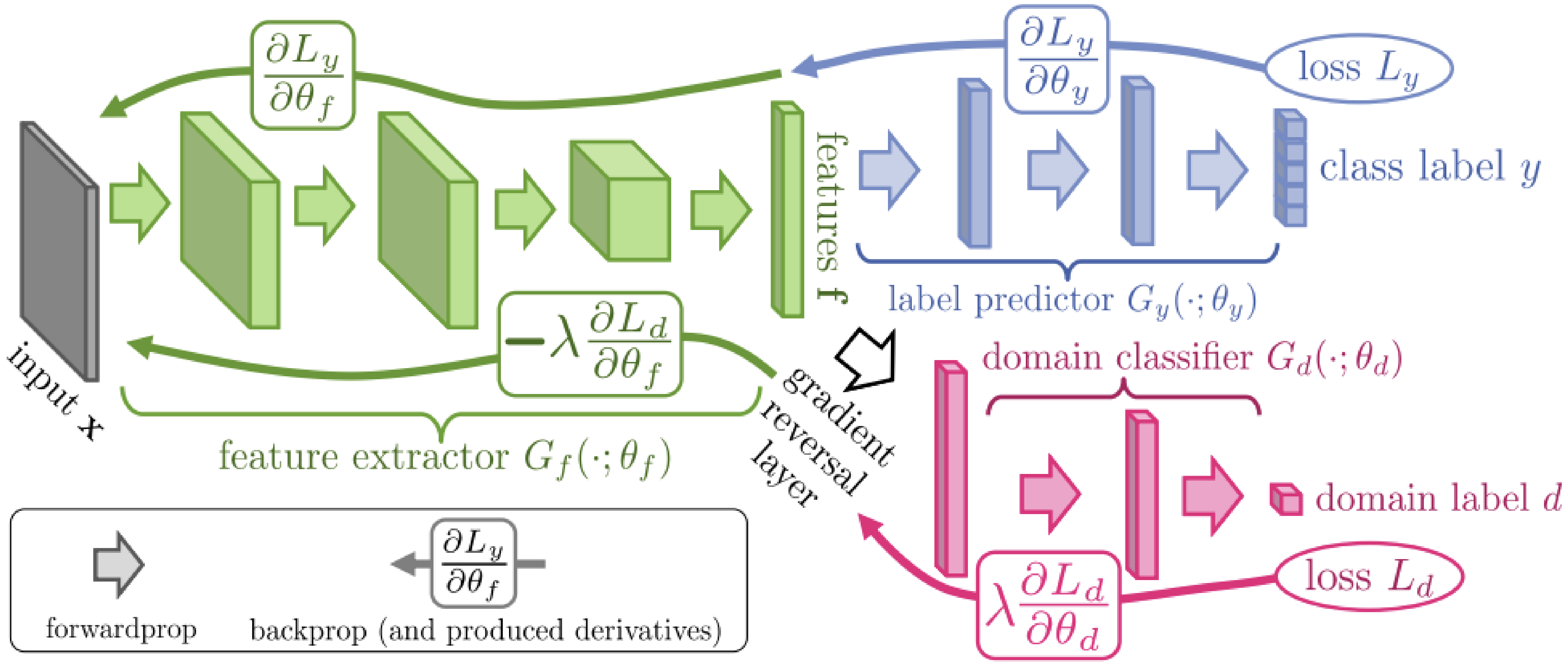
Auto-encoder:





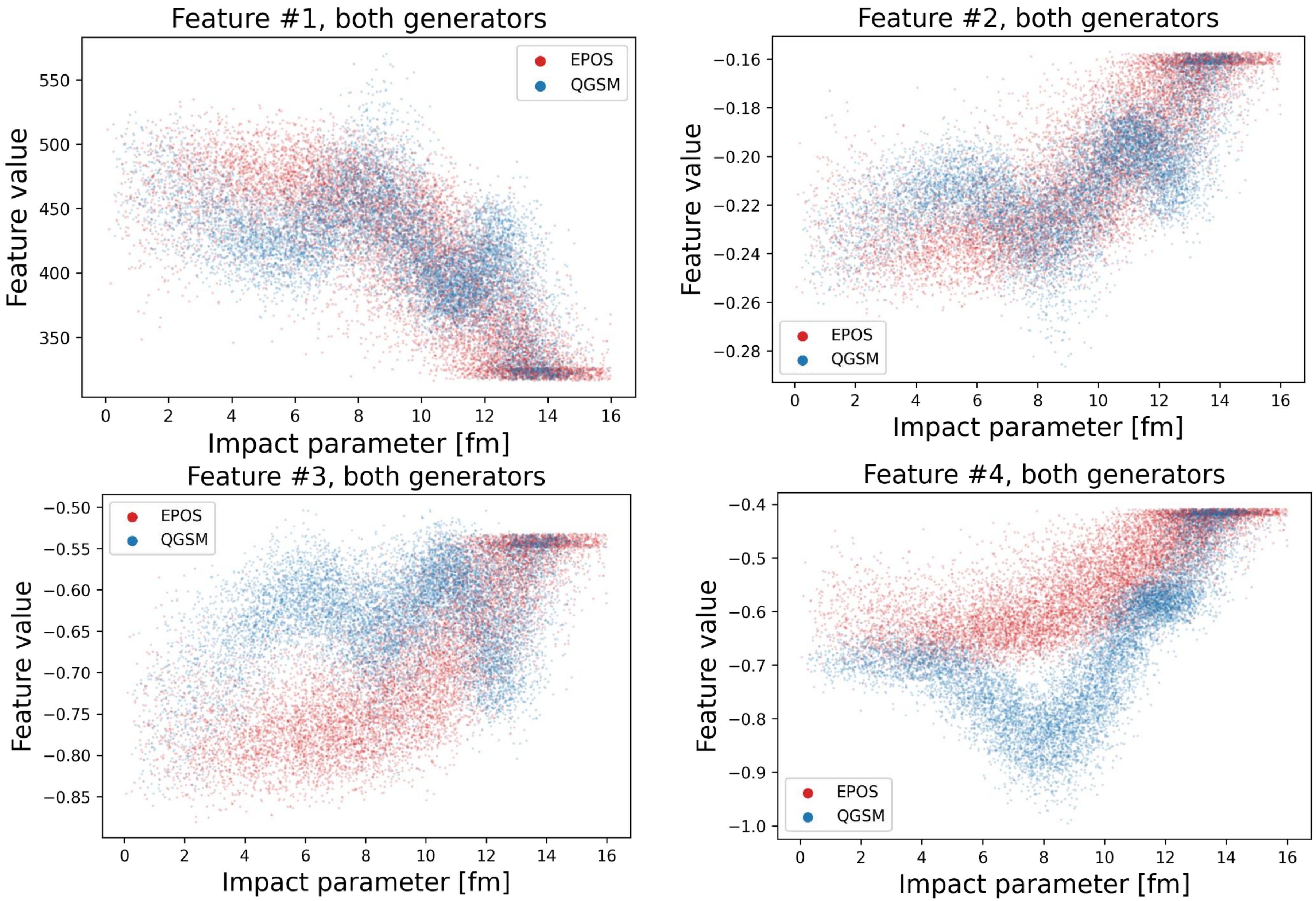


Domain adaptation: Domain-adversarial neural network[1]

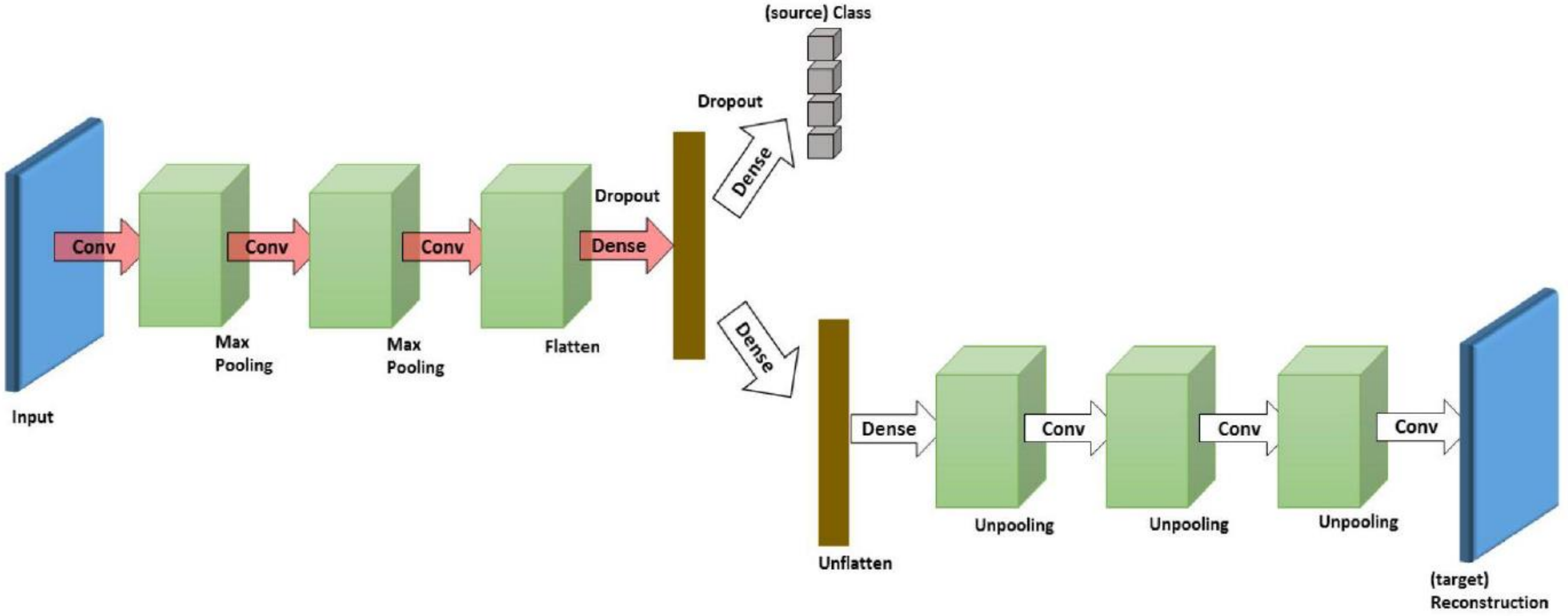


[1] Mei Wang, Weihong Deng, “Deep visual domain adaptation: A survey”

Domain-adversarial neural network, extracted features



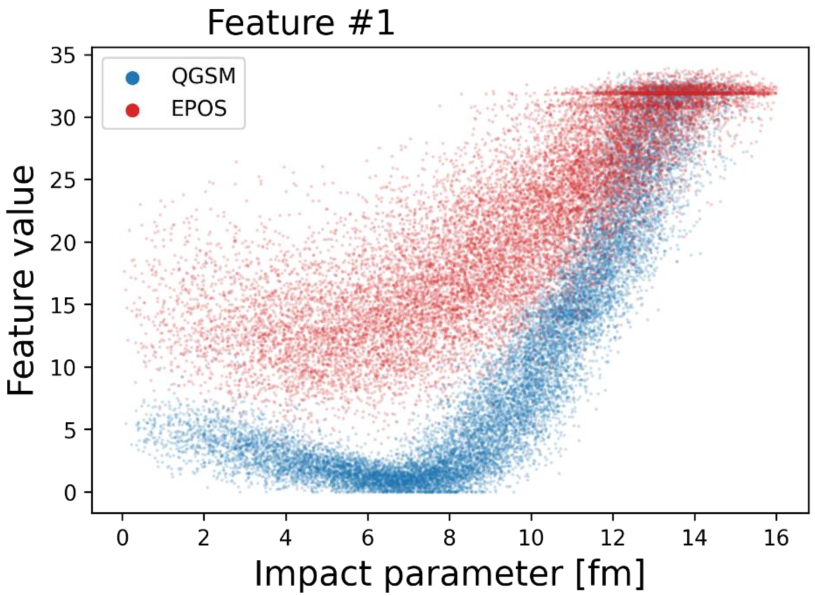
The deep reconstruction neural network (DRNN)[1]

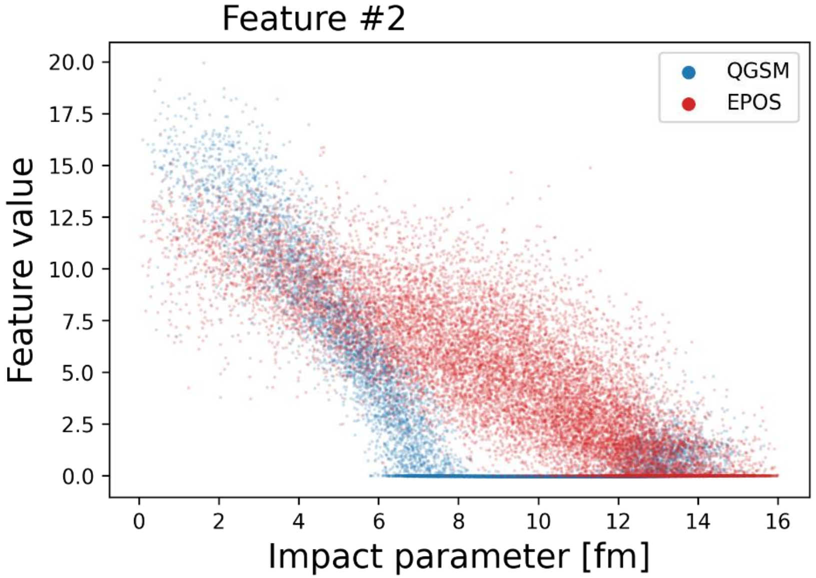


[1] Mei Wang, Weihong Deng, "Deep visual domain adaptation: A survey"

The deep reconstruction neural network. New features.

QGSM & EPOS





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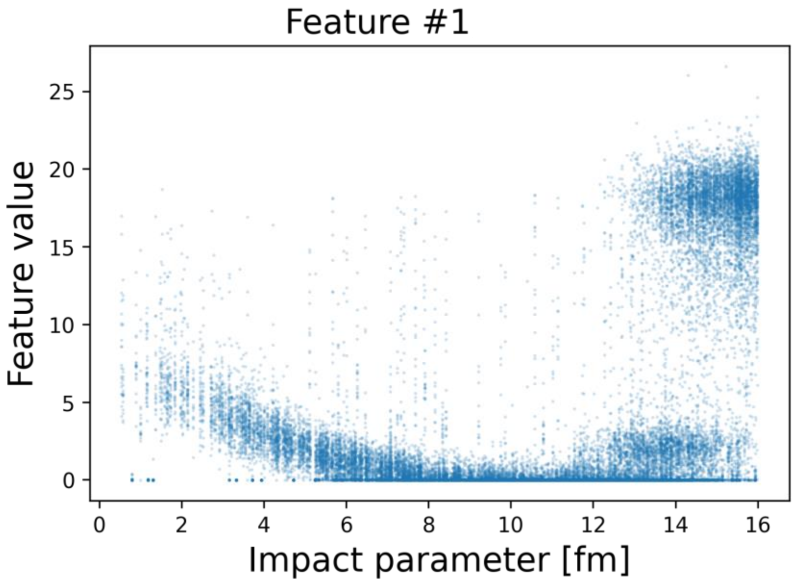
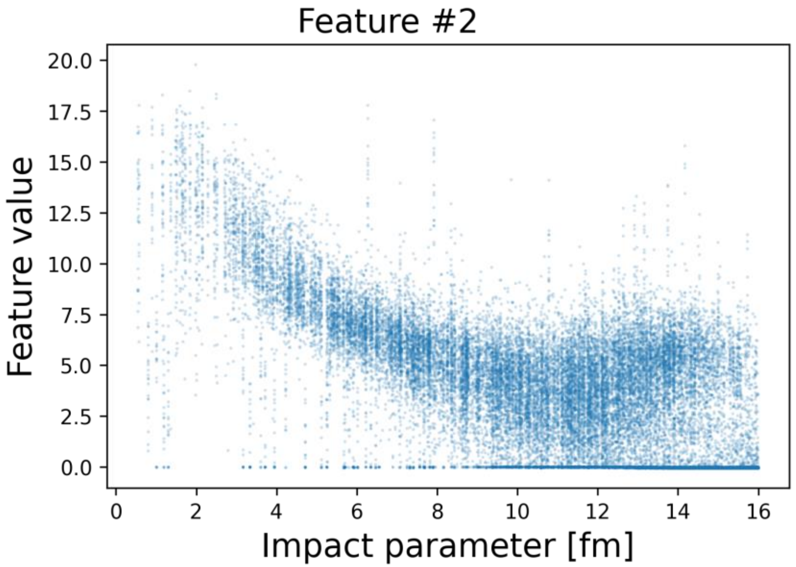
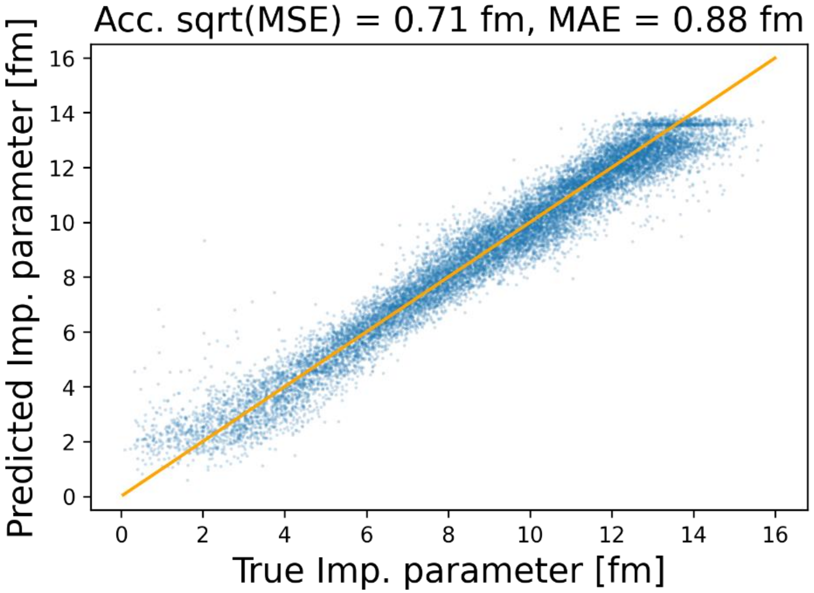


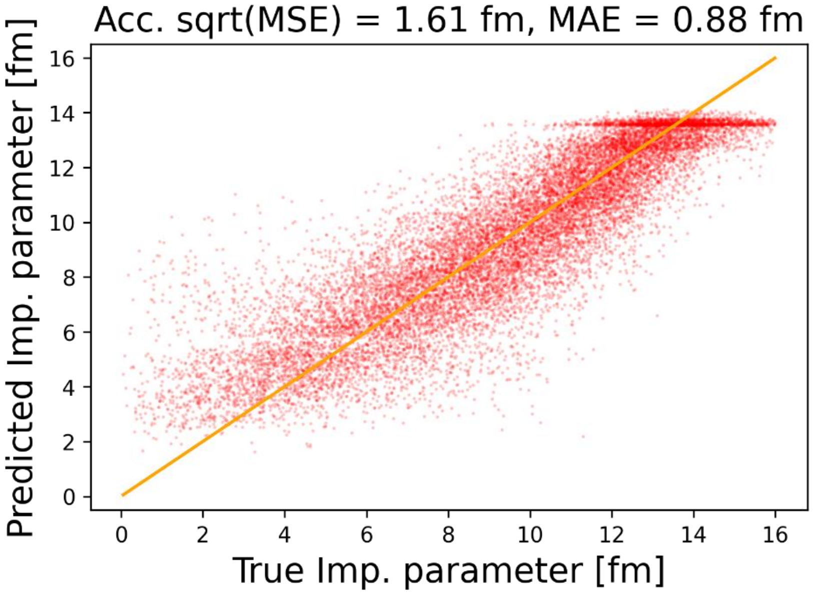


The deep reconstruction neural network. Results.

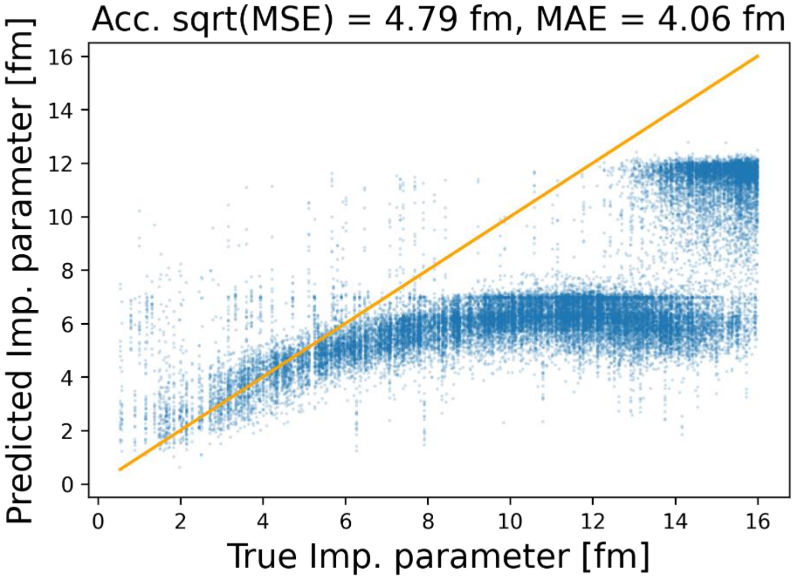
Tests on: QGSM



EPOS



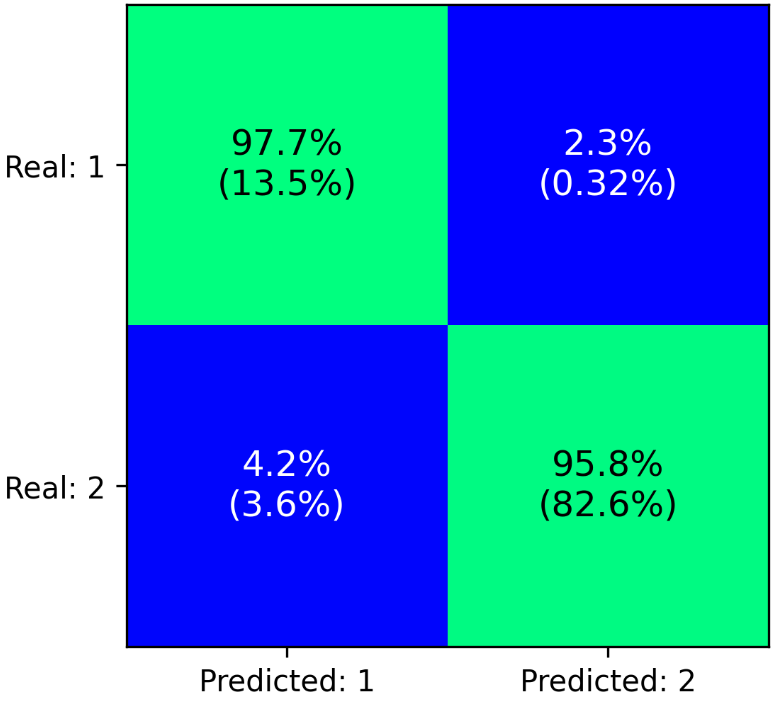
PHQMD



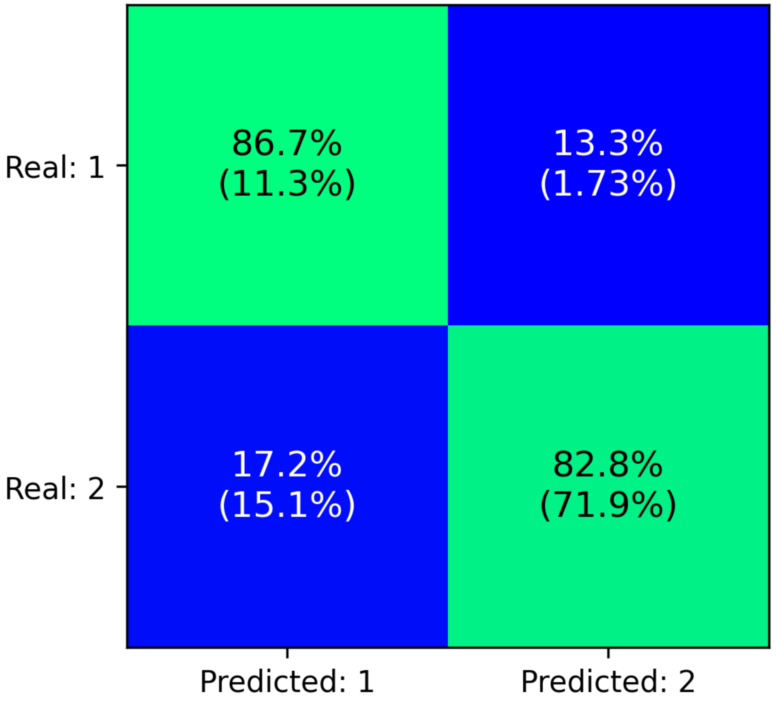
The deep reconstruction neural network. Results for the classification problem.

The goal of the network here is to label central collisions with b < 5 fm.

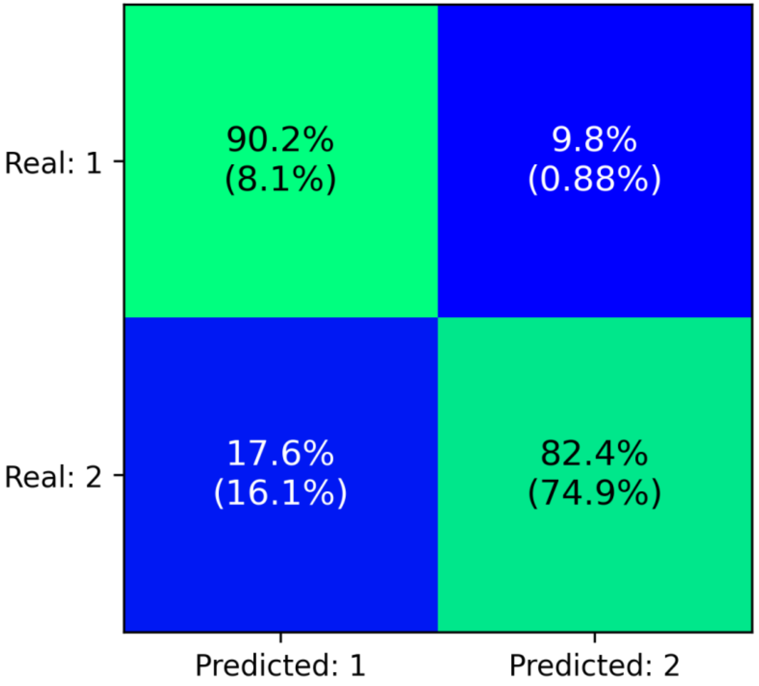
Tests on: QGSM



EPOS



PHQMD



Conclusions

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Hidden dependencies

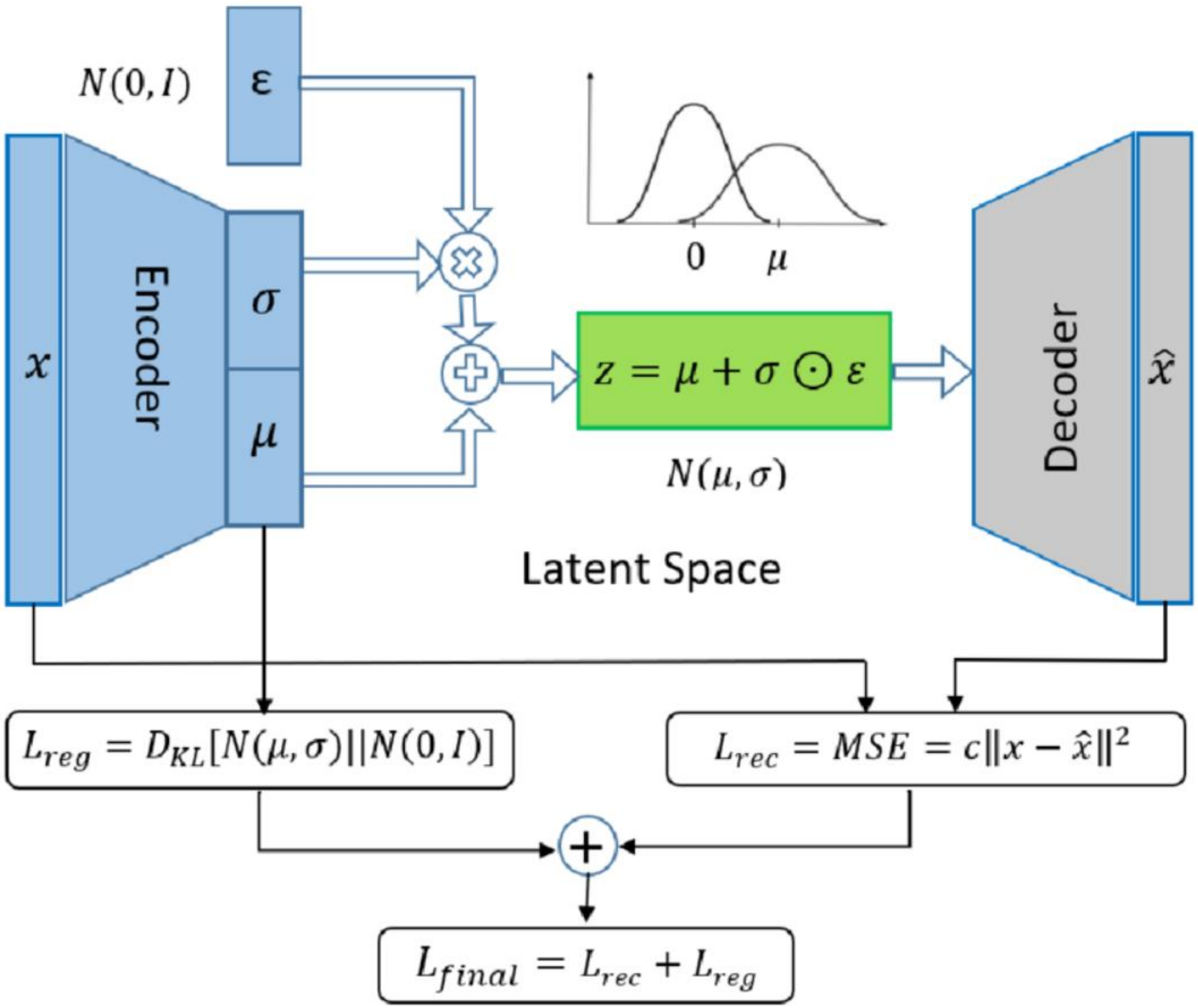
With the help of artificial neural networks, it has become possible to extract hidden patterns in data from different sources.

New methods are worth researching

Investigated methods are capable of working simultaneously with data from different event generators.

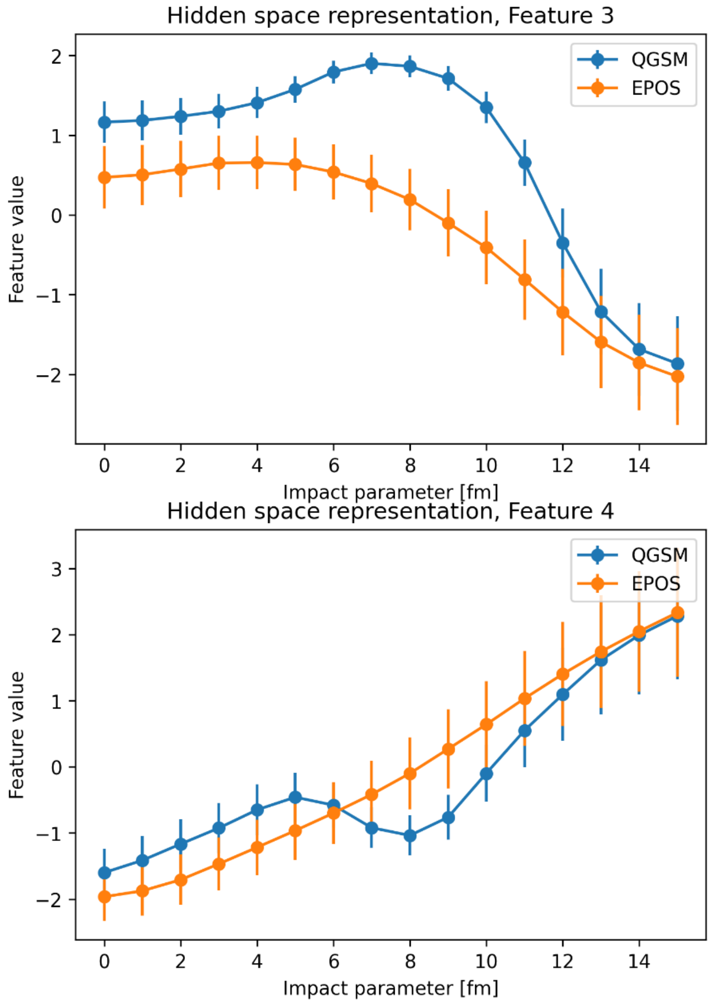
The authors acknowledge Saint-Petersburg State University for a research project 103821868

Using variational autoencoder (VAE) as the domain adaptation technique

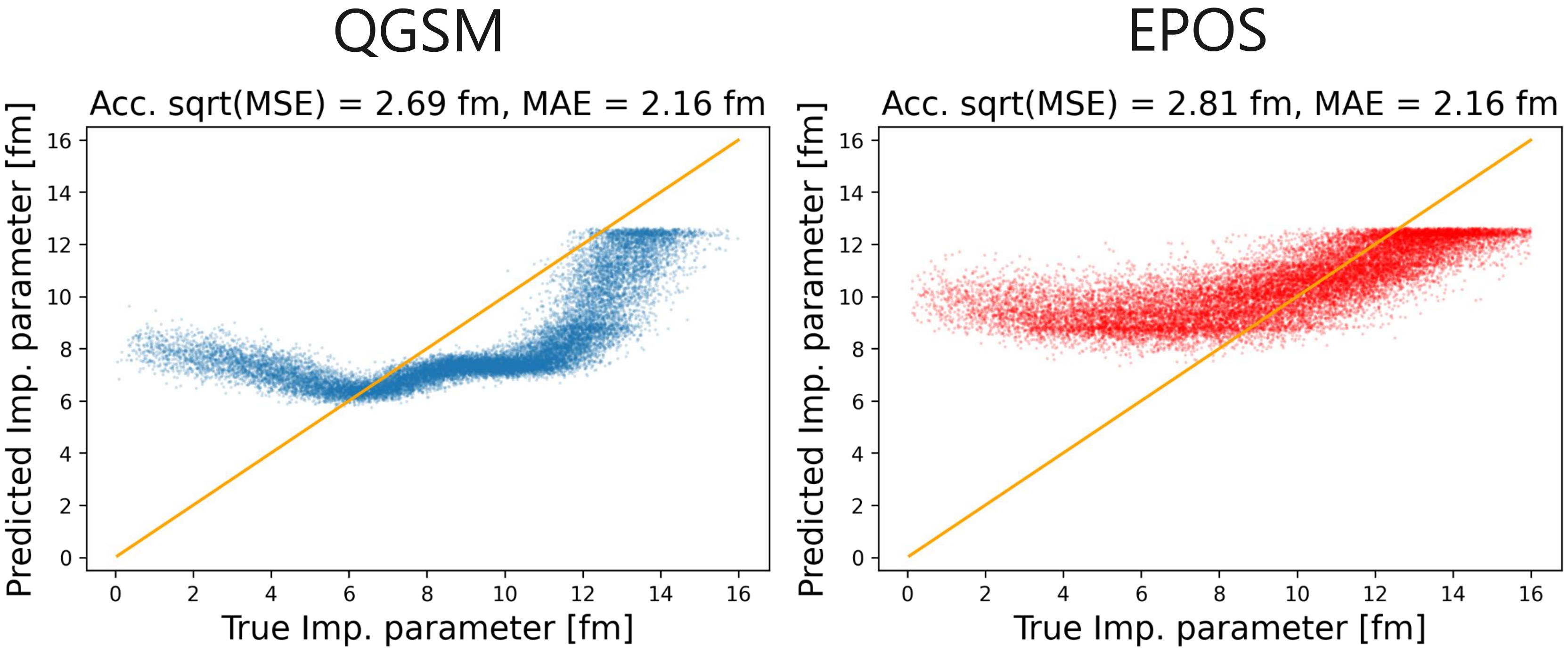


Variational autoencoder results

While the use of variational autoencoders can result in meaningful event features, the results of impact parameter estimation are worse than with other techniques.



VAE features



Regression results