Using convolutional neural networks for HiSCORE events analysis

VLASKINA ANNA, FACULTY OF PHYSICS, MSU

ALEXANDER KRYUKOV, SINP MSU

5th International Workshop on Deep Learning in Computational Physics, 2021

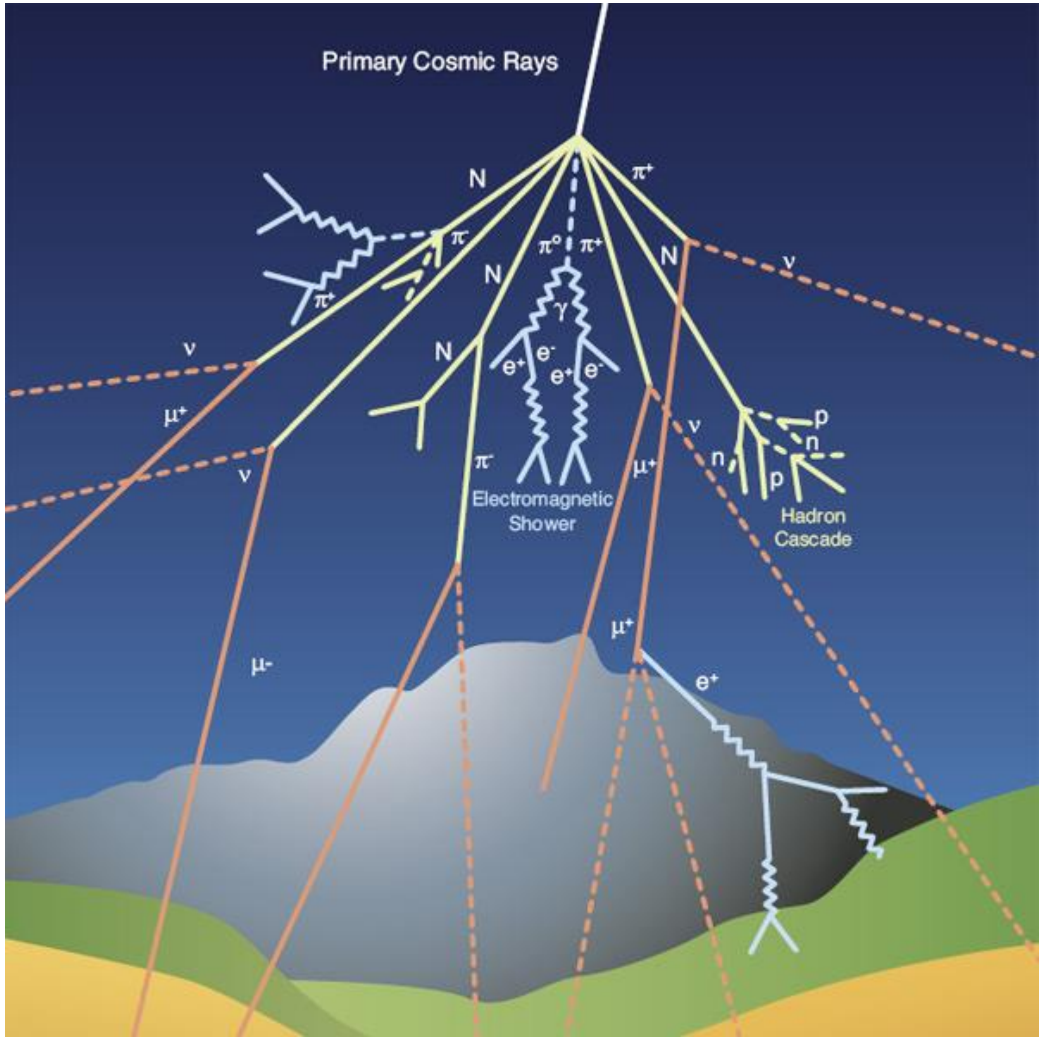
Gamma astronomy

Physical problems of gamma astronomy:

- Study of physical phenomena, occurring in extreme conditions
- Principles of acceleration of ultra-high energy particles and the search for their sources in the universe.

Methods: Extensive Air Showers

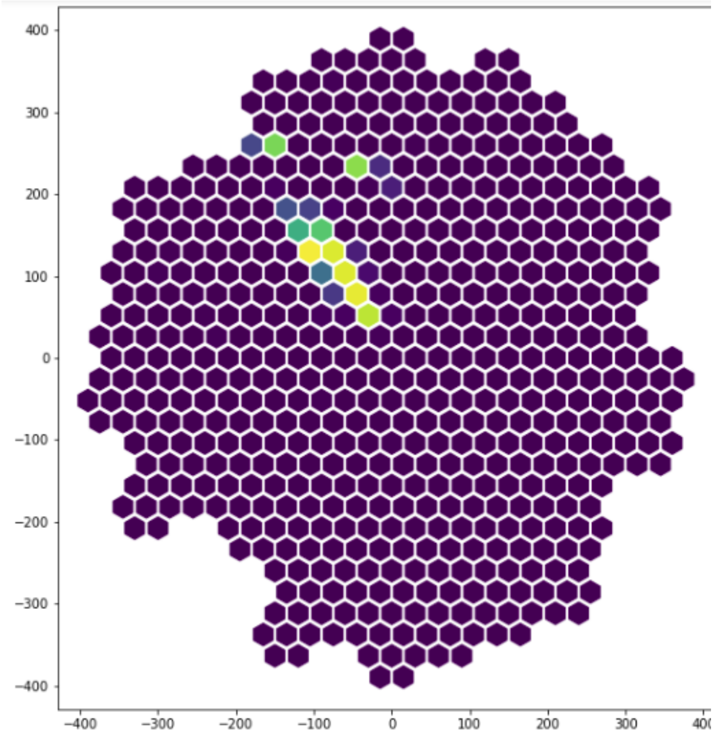
- Primary high-energetic particle reaches the atmosphere, generating a massive cascade of secondary particles.
- Secondary particles emit Cherenkov light
- Air shower parameters: primary particle type, its arrival direction, position of central axis, particle energy
- Conventional method of parameter determination: Hillas parametrization



TAIGA experiment
(Tunka Advanced Instrument for cosmic rays and Gamma Astronomy)

- Instrument for ground-based astronomy from a few PeV to several TeV
- Consists of Cherenkov Telescopes (TAIGA-IACT), Cherenkov stations (TAIGA-HiSCORE), scintillation counters and other instruments.

TAIGA-IACT
and TAIGA-HiSCORE



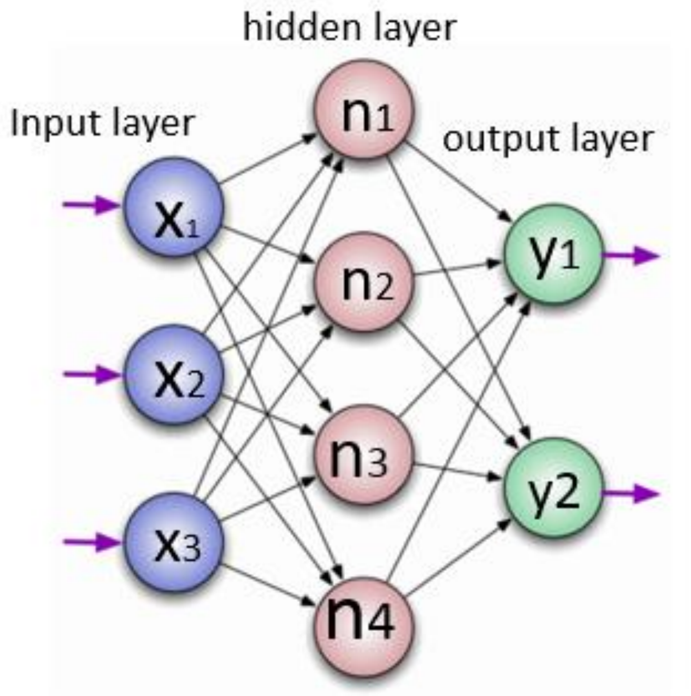
IACT-event (Monte-Carlo simulation)

Artificial Neural Networks (ANN)

Value of the hidden layer node:

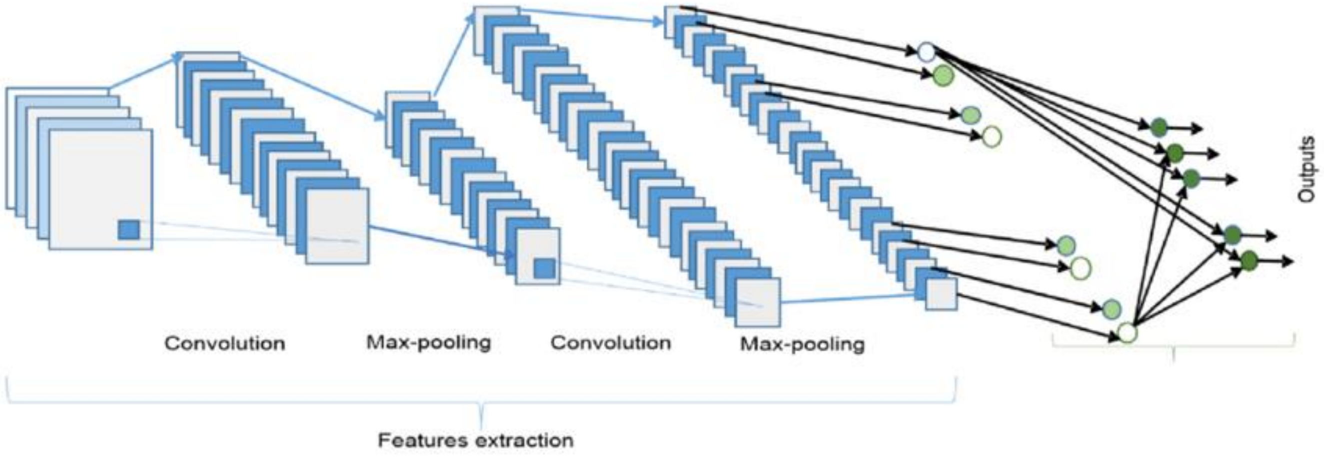
$$n_k = w_{k1}x_1 + w_{k2}x_2 \ldots + w_{kn}x_n + w_0$$

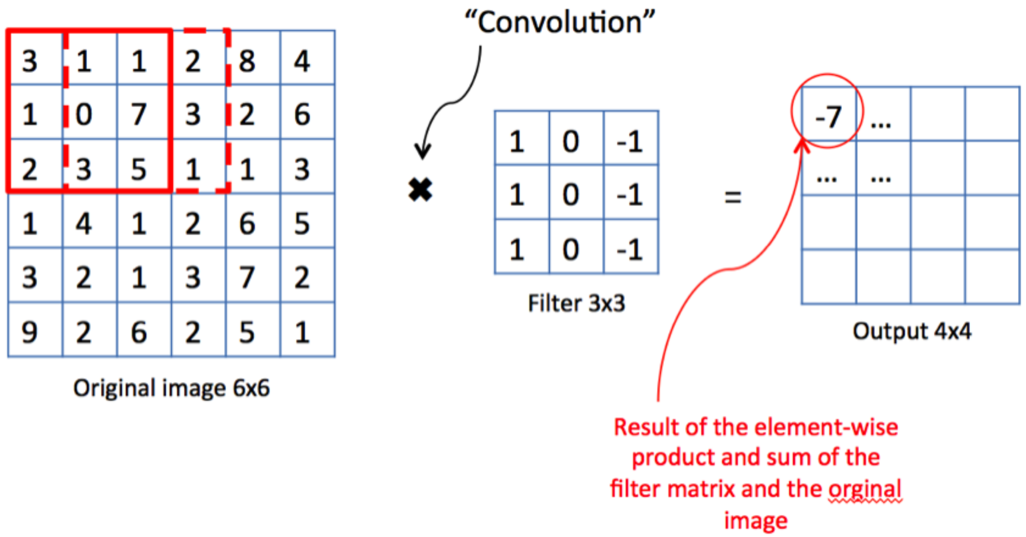
The goal of training is to find the local minimum of the error function of the weights. To find the local minimum, the gradient descent method is used.



Convolutional Neural Network (CNN)

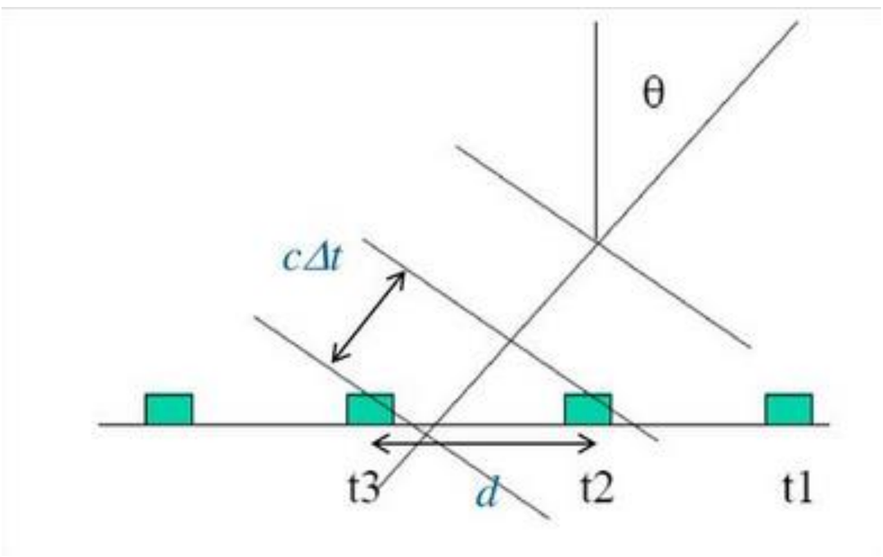
The main feature of CNN is operation of convolution.
It is used mostly for data with grid topology, such as images.

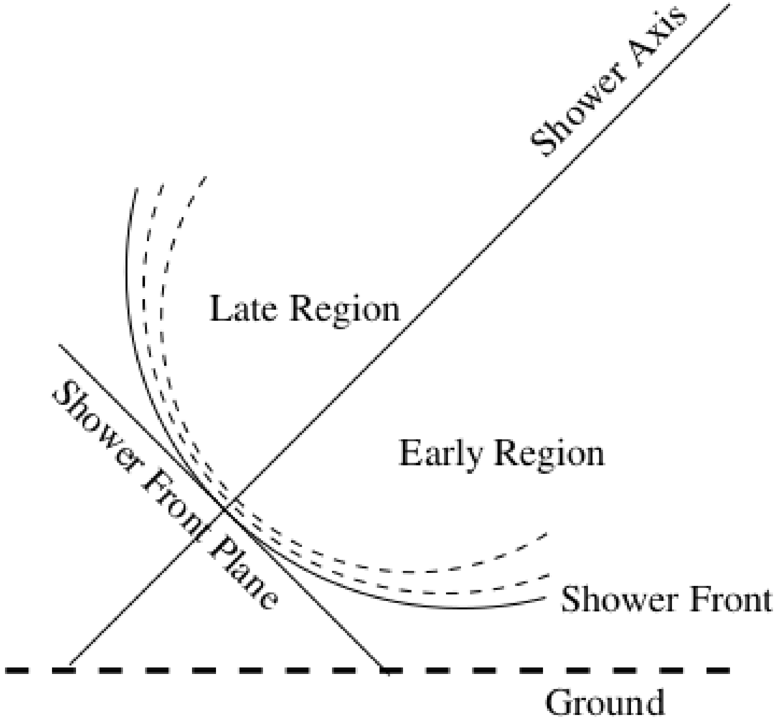




Conventional analysis methods

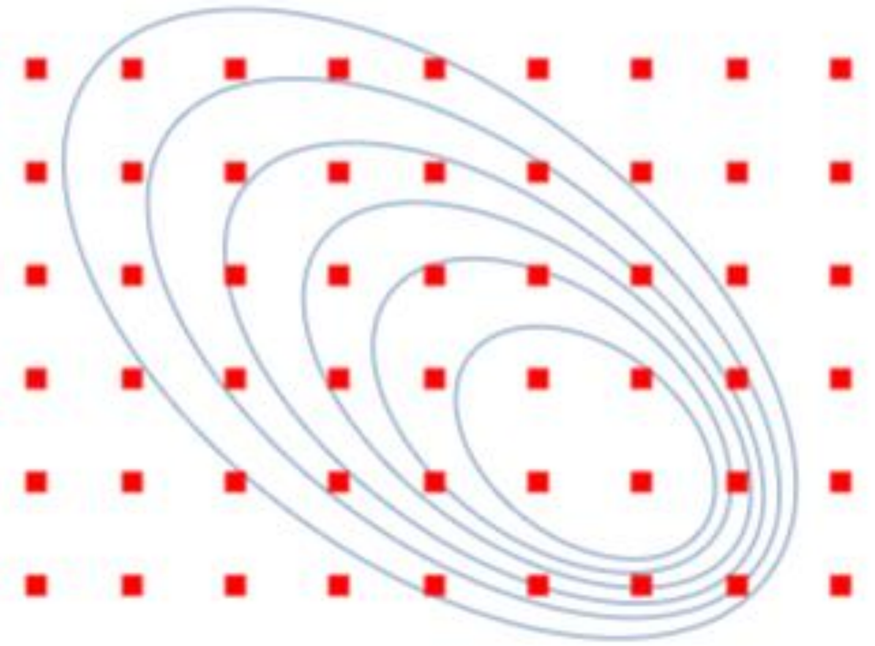
Traditional method of analysis: Searching for the EAS front





Proposed method

- We consider a set of times of signal arrival registration as an "image“.
- We are looking for a time isoline and use them to restore the direction of the EAS axis
- For time isoline determination, deep learning technologies can be used, in particular, we propose the use of a CNN

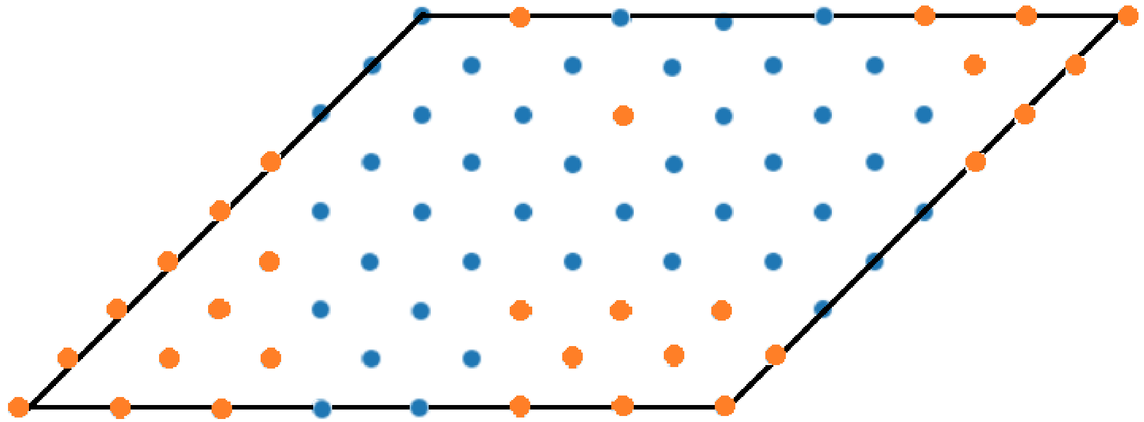


- Data: Monte-Carlo events

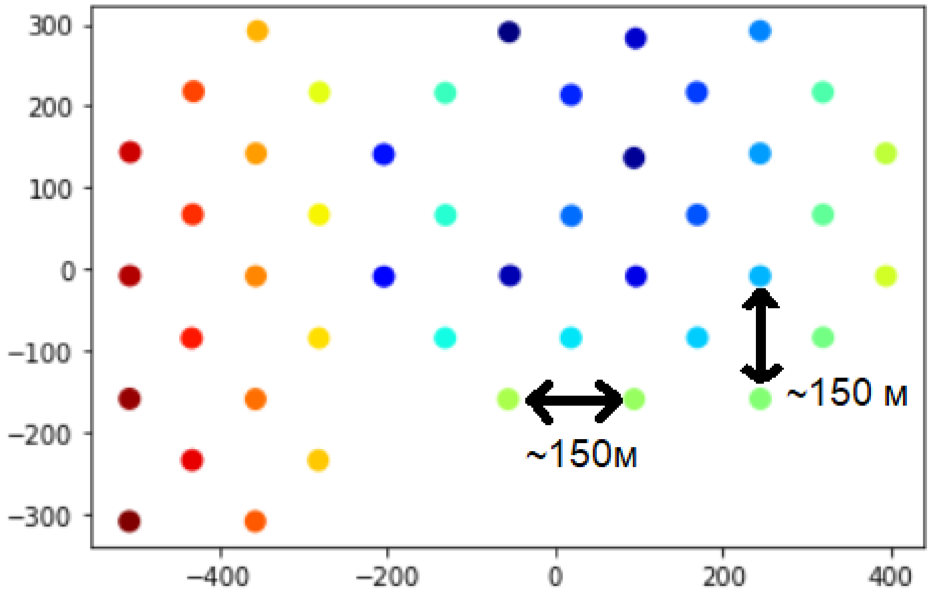
We use the time of registration of the signal by the station as input data

- At the output of the network, we expect the values of the polar and azimuthal angles
- We work with data for 44 stations
- It is necessary to bring the grid of stations to a rectangular form

Rectangular grid of HiSCORE stations: added points are marked in orange



Position of HiSCORE stations



Model architecture

№	Layer type	Output shape	Number of output filters	Activation function
1	Convolutional 2D	9x9x27	27	ReLU
2	Convolutional 2D	9x9x9	9	ReLU
3	Convolutional 2D	9x9x3	3	ReLU
4	Flatten	243	-	-
5	Dense	72	-	ReLU
6	Dense	36	-	ReLU
7	Dense	18	-	ReLU
8	Dense	2	-	ReLU

Model architecture

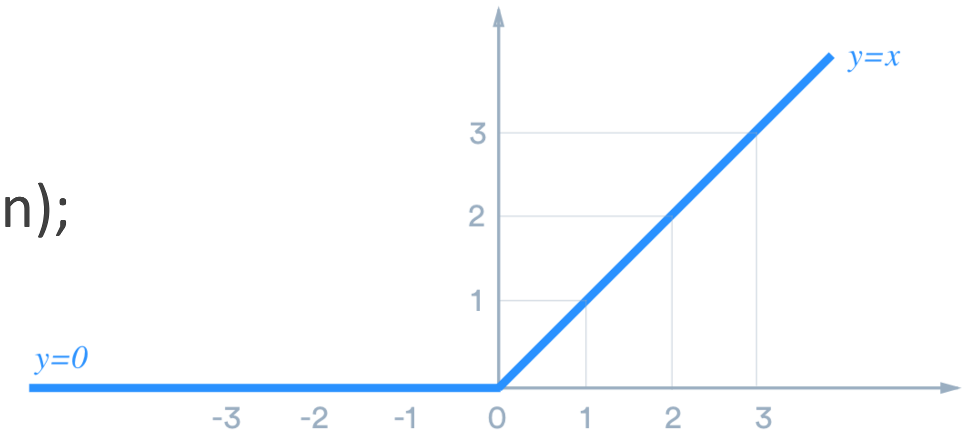
Kernel size: 3 x 3

Total number of parametrers: 23612

Optimizer: ADAM (Adaptive Moment Estimation);

learning rate = 0,001

Loss: $MSE = \frac{1}{n}\sum_{i}^{n} \quad (y_{true} - y_{pred})^2$



ReLU activation function

Training results

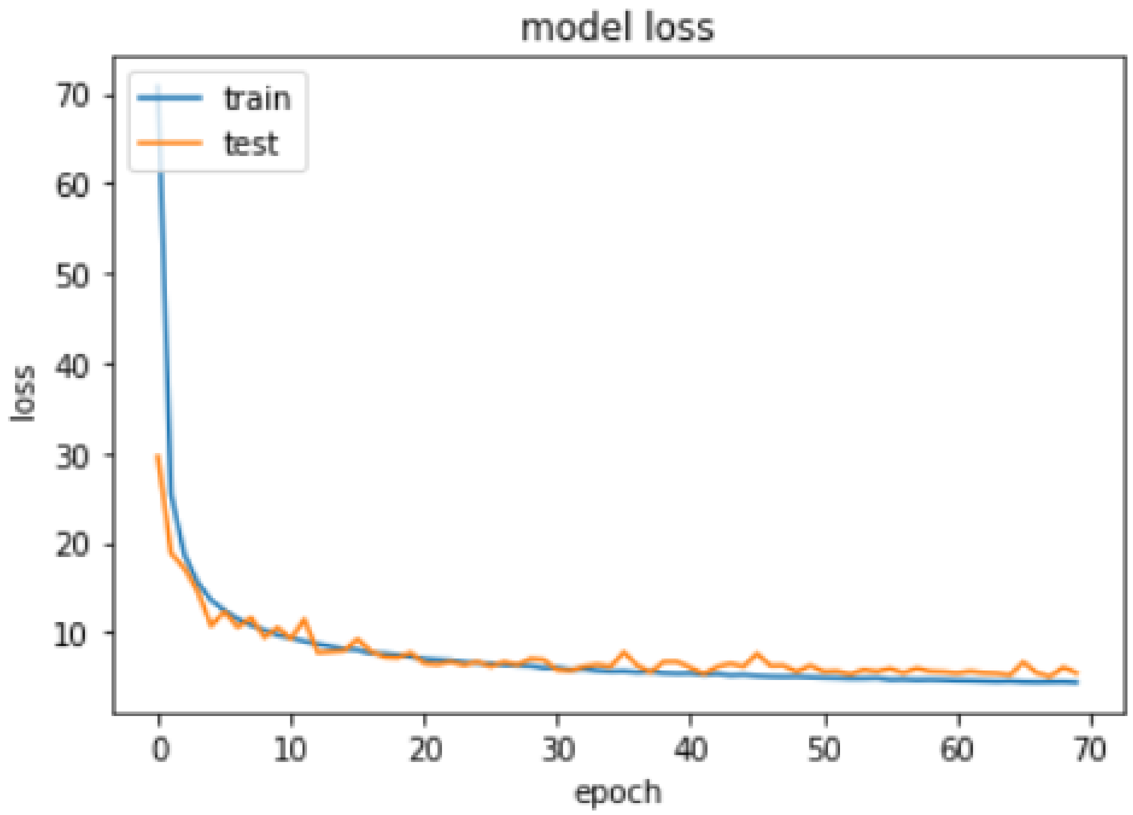
Accuracy: ~95%
MSE = 5.09

Mean Absolute Error:

$$MAE = \frac{1}{N}\sum^{N} \quad |y_{true} - y_{pred}\,|$$

Mean absolute error for Theta: 1.34°

Mean absolute error for Phi: 1.82°



Number of epochs: 70
loss: MSE

Training results

Events with more than 10 points:

Mean absolute error for Theta: 1.30°

Mean absolute error for Phi: 1.76°

Events with less than 10 points:

Mean absolute error for Theta: 1.85°

Mean absolute error for Phi: 2.79°

Training results

Number of stations: above 10.

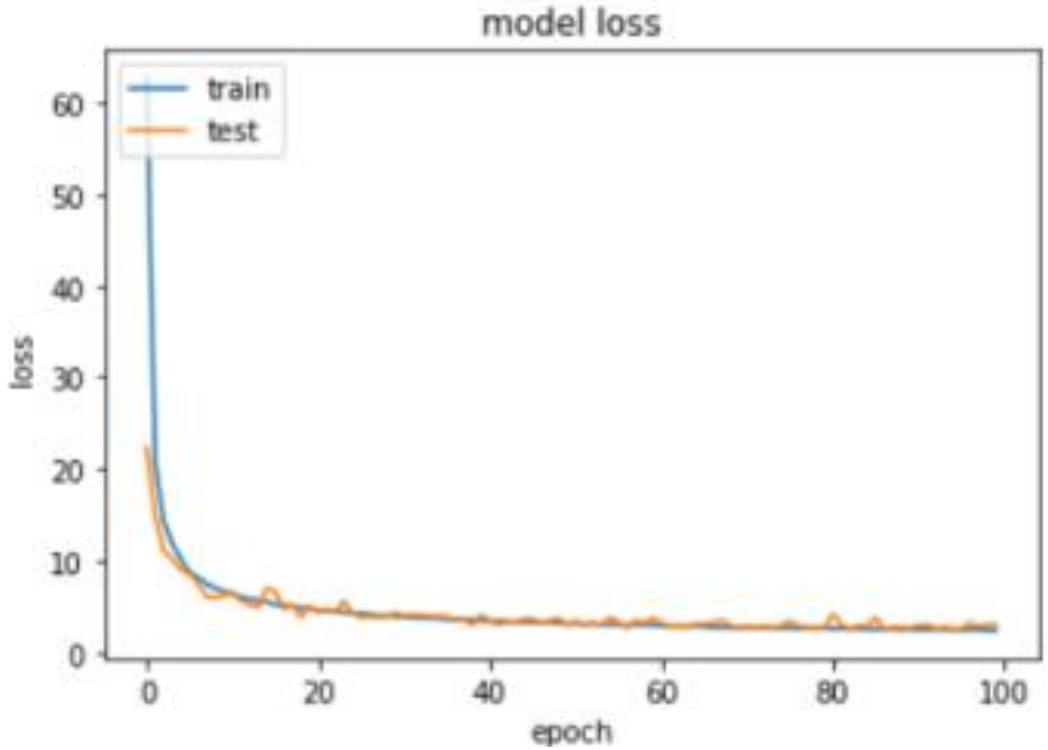
Training set: 36128 events

Validation set: 500 events

Number of epochs: 100

Mean absolute error for Theta: 1.04°

Mean absolute error for Phi: 1.70°




```
loss:  3.0585246086120605   accuracy:  0.9760000109672546
Mean absolute error for Theta: 1.0384769001007081
Mean absolute error for Phi: 1.7023339276313783
```

Training results

Number of stations: below 10.

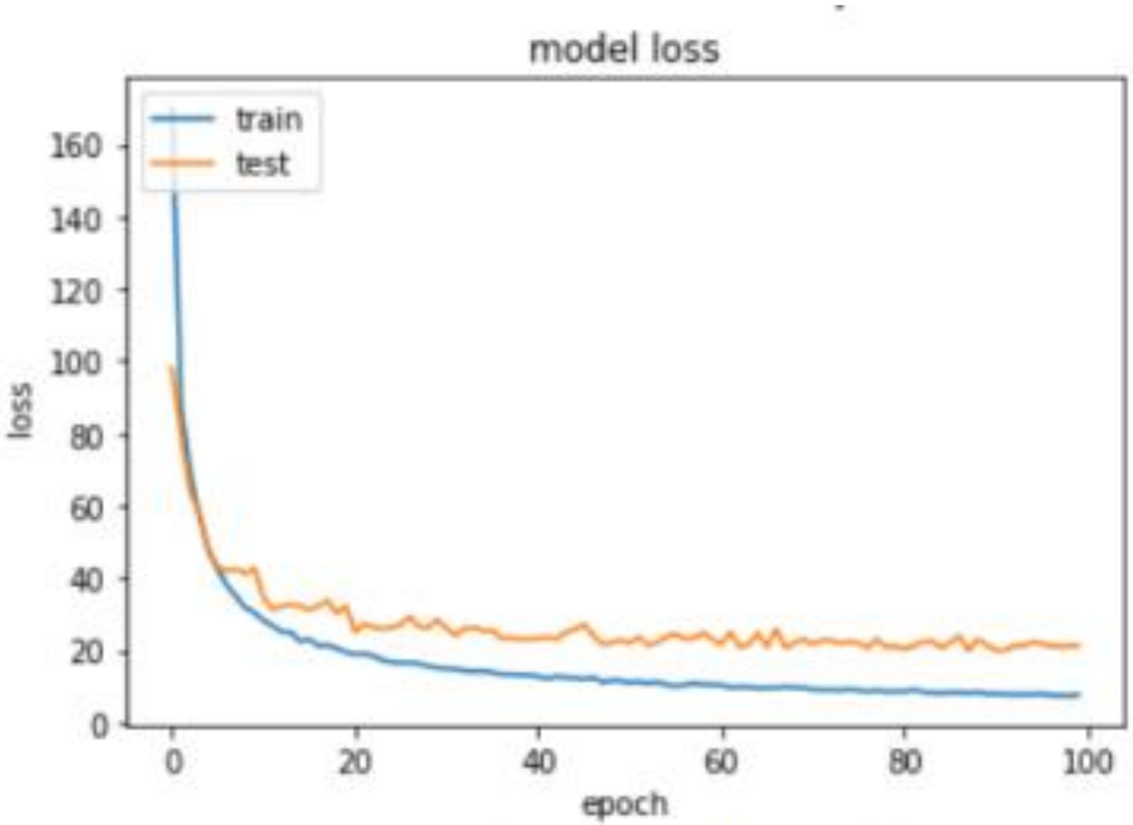
Training set: 8736 events

Validation set: 500 events

Number of epochs: 100

Mean absolute error for Theta: 2.32°

Mean absolute error for Phi: 3.85°




```
loss:  21.11964225769043   accuracy:  0.921500027179718
Mean absolute error for Theta: 2.3196171808242796
Mean absolute error for Phi: 3.8468647526502604
```

Conclusions

Achieved accuracy of angle determination: 95%

CNN applications in TAIGA experiment has promising results

Perspectives:

- Taking into account that real grid is irregular: linear interpolation of times is proposed
- Applying deep learning technologies to determine the EAS energy, the position of the EAS axis
- Considering different network architectures for pattern recognition

Thank you for your attention!