# Fast Simulation of a Cherenkov Telescope Event Images in the TAIGA Experiment: Current Status

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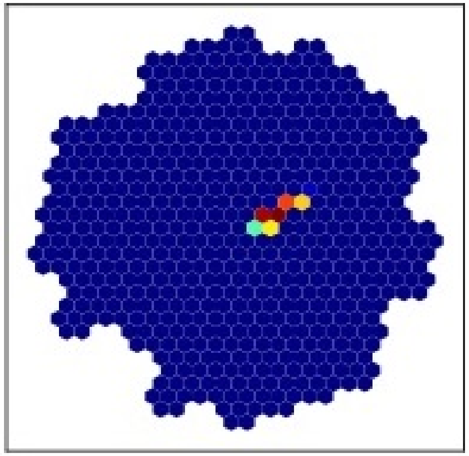
22.04.2021

# What is an event image?

Charged cosmic rays and high energy gamma rays interact with the atmosphere.

The result is extensive air showers of secondary particles emitting Cherenkov light.

TAIGA-IACT telescopes detect the light.



Detected data form "images" of the air shower.

Directly recorded data and model data are widely used.

# Task and goal setting

## Current situation:

Images of gamma and proton events are modeled using a special program (CORSIKA) that performs detailed direct simulation of extensive air showers, thereby producing reasonably accurate but resource-intensive and time-consuming results.

Only about 1000 images are generated in an hour!

## The goal: simulate images of gamma and proton events quickly and still accurately

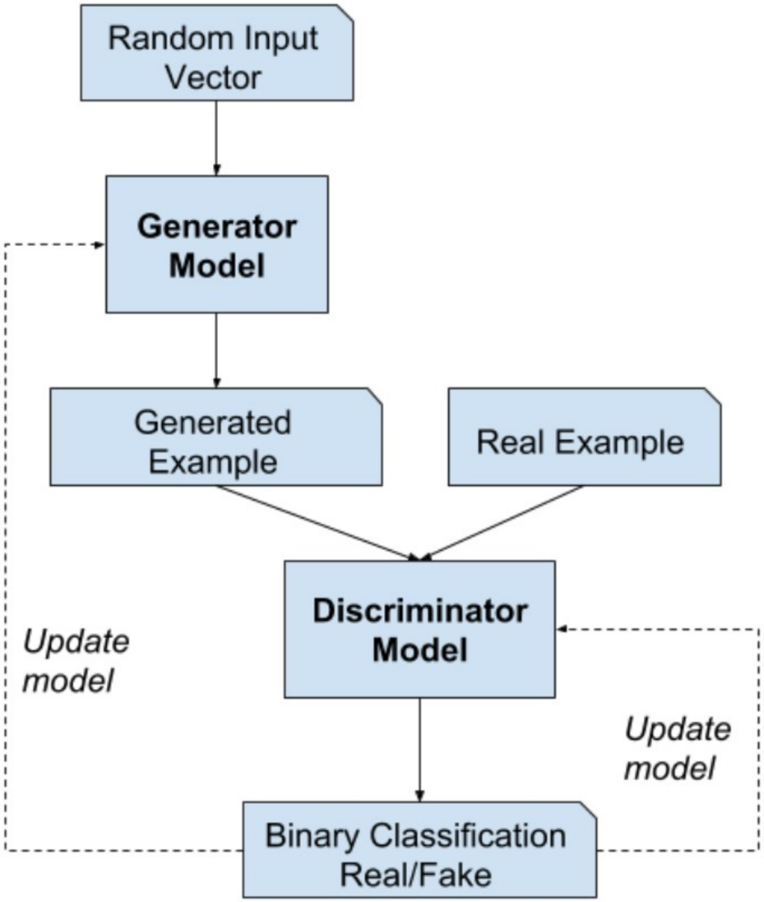
# Generative adversarial network (GAN)

GANs are an approach to generative modeling using deep learning methods, such as neural networks. Each GAN consists of two parts: a generator and a discriminator.

Generator:
a neural network that tries to transform its random input into images similar to the real ones

Discriminator:
a neural network that tries to distinguish between real images and those produced by the generator

Generator and Discriminator are trained together on real images in an adversarial game, until the discriminator model is fooled about half the time, meaning the generator model is generating plausible examples.



# Training dataset preparation

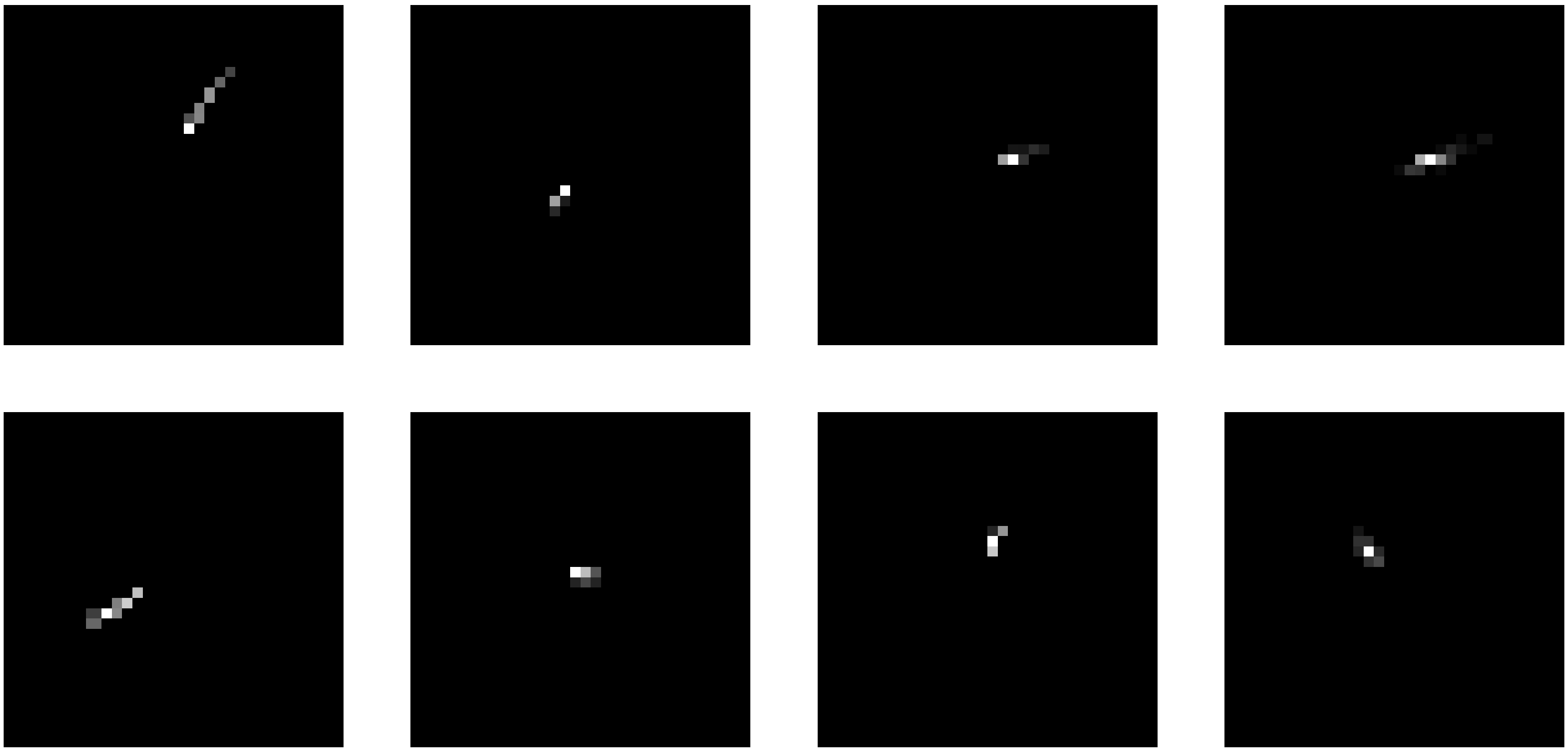
Our GAN was trained on a sample of two-dimensional images obtained using TAIGA Monte Carlo simulation software, containing about 25,000 events of each of the two types: gamma and protons events.

To increase the sample size and account for rotational symmetry, each gamma image of the training set was rotated around the center 5 times by 60 degrees.

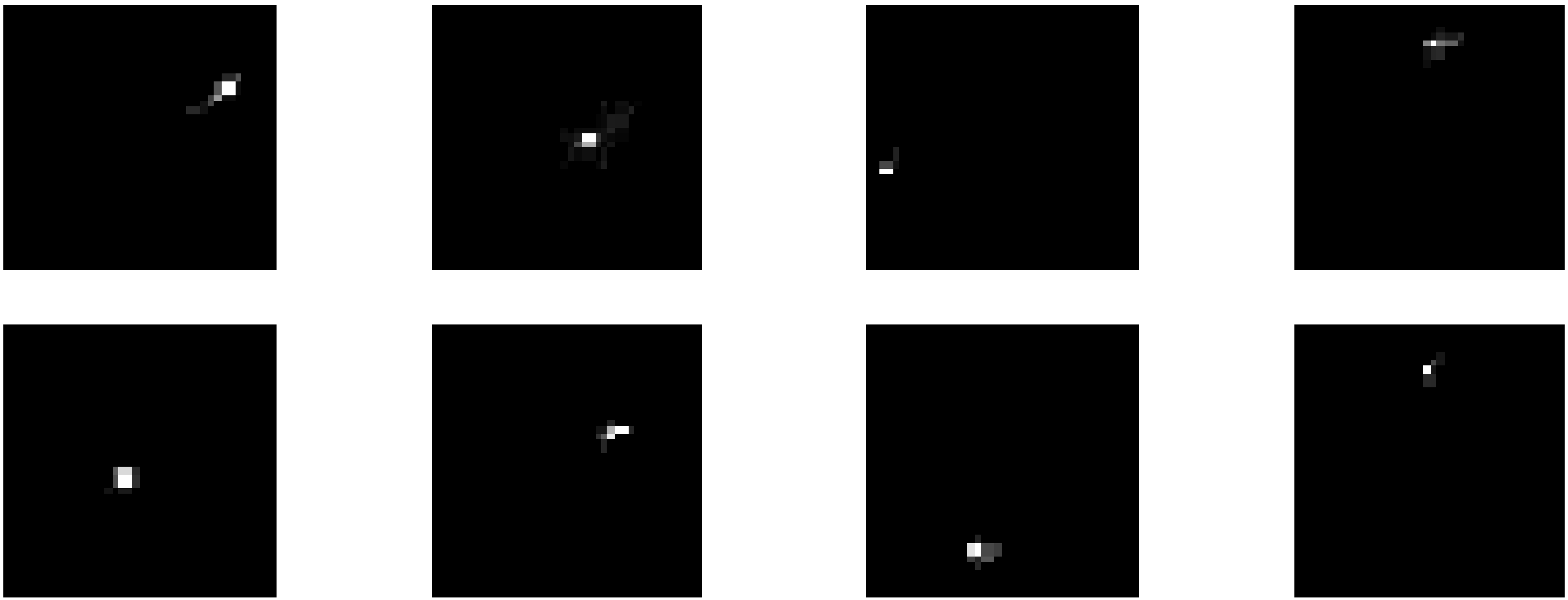
The original images recorded by the telescope's hexagonal lattice were transformed into images with a size of 31 by 30 pixels by transition to an oblique coordinate system. Because GANs work best with square images, each image has been converted to 32 by 32 pixels by adding zeros.

Since the training set contained events with different energies, we had to switch to a logarithmic scale by applying the logarithm function to each pixel of each image: $\ln(1+x)$.

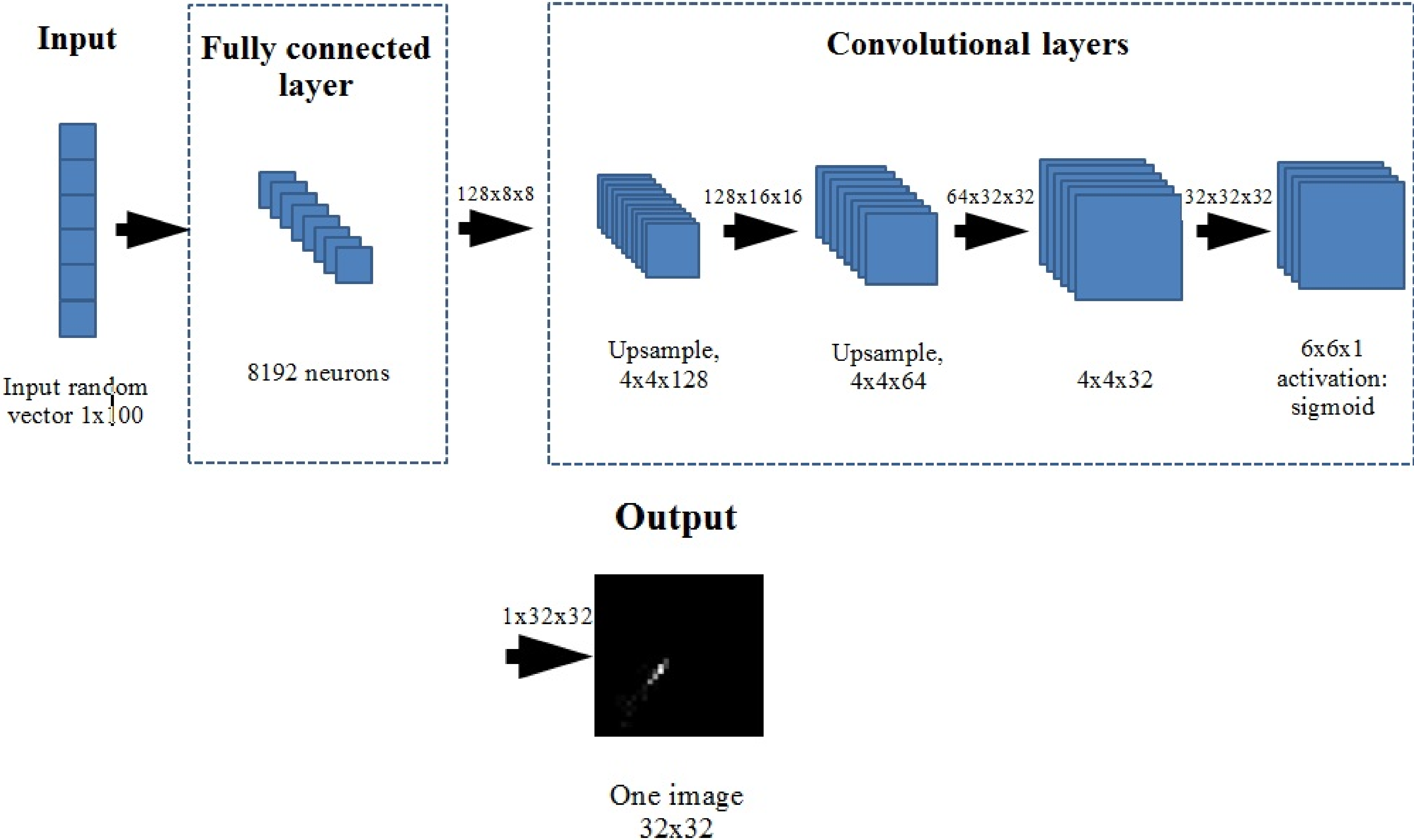
# Training dataset examples.
# Gamma images



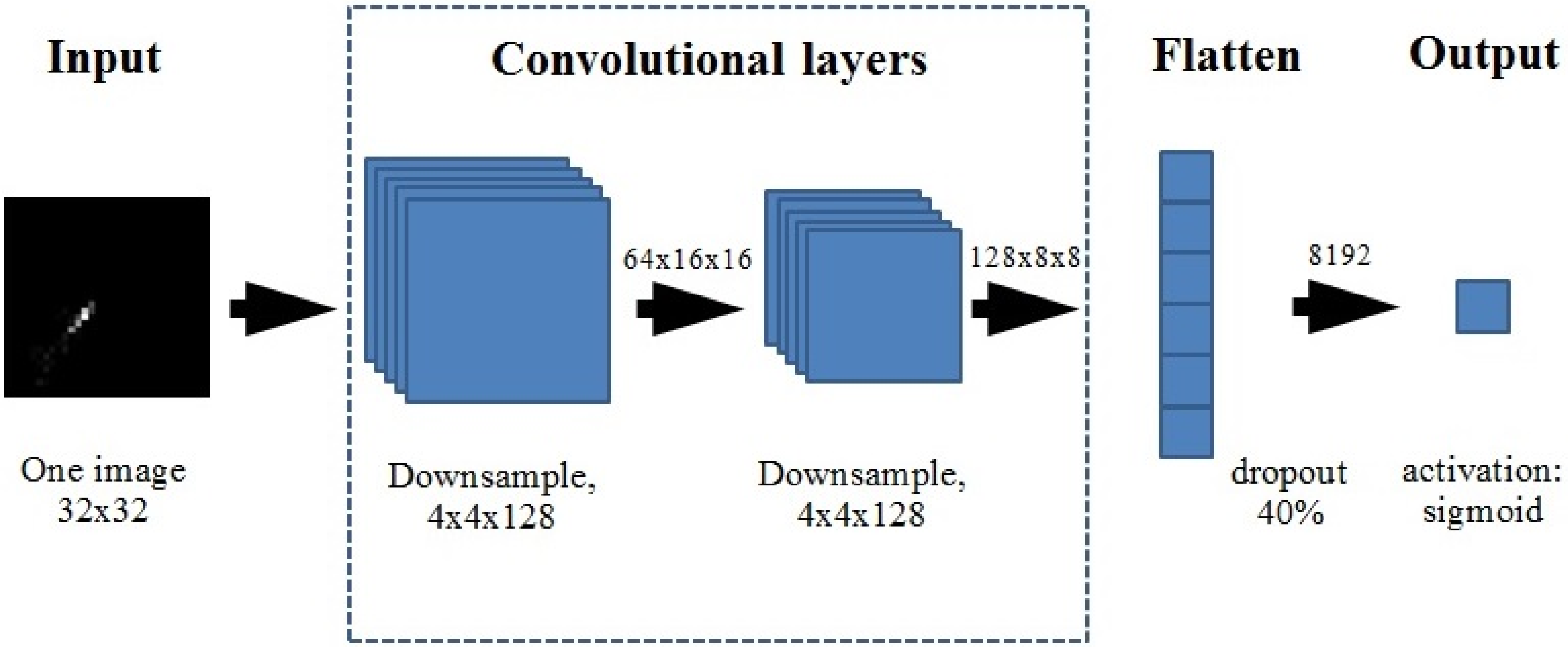
# Training dataset examples.
# Proton images



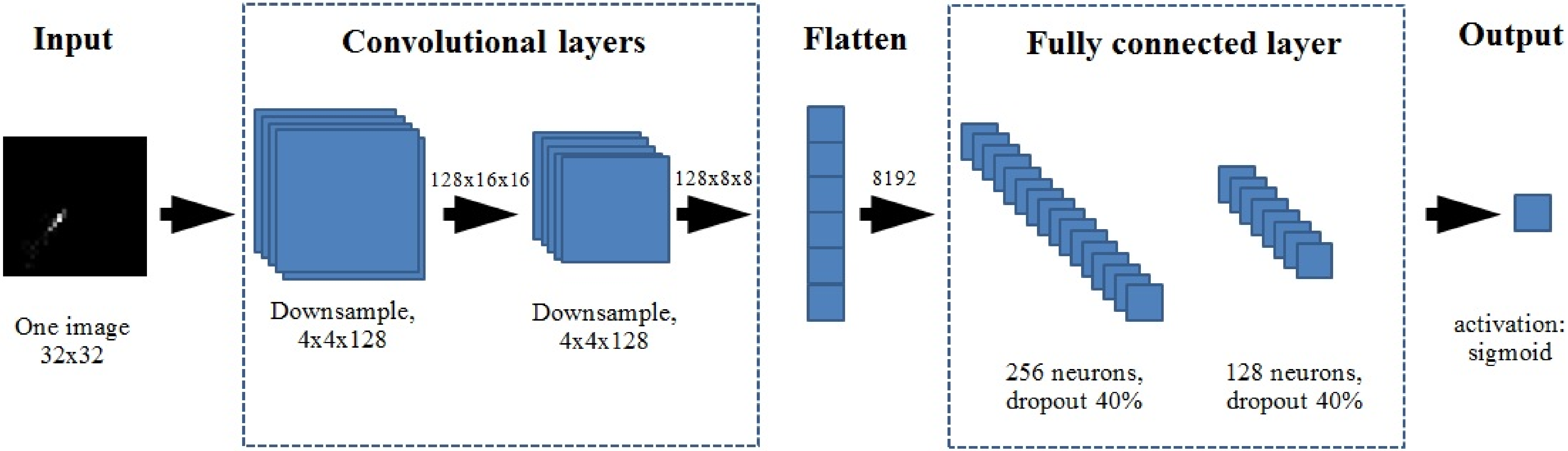
# Generator architecture



# Discriminator architecture for gamma

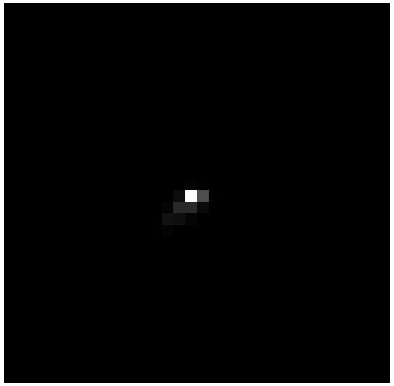
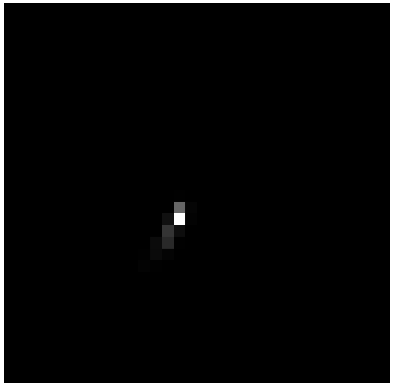
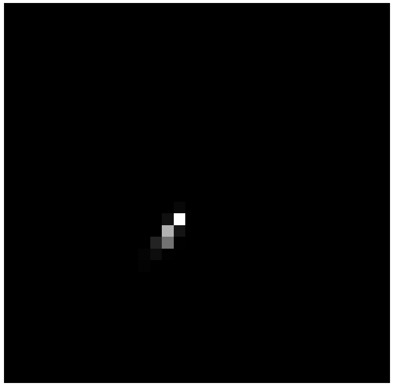
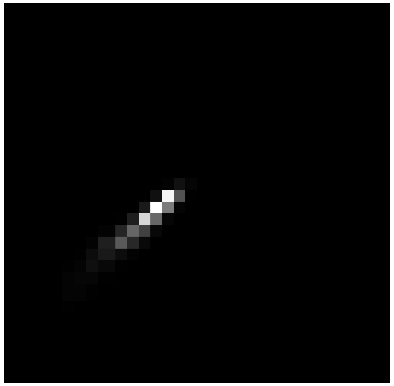


# Discriminator architecture for protons

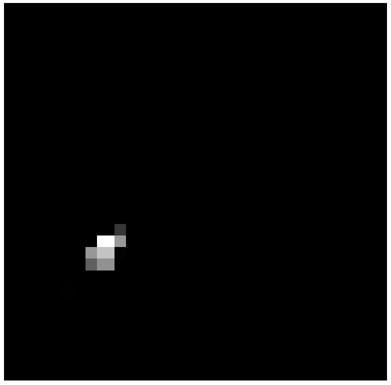
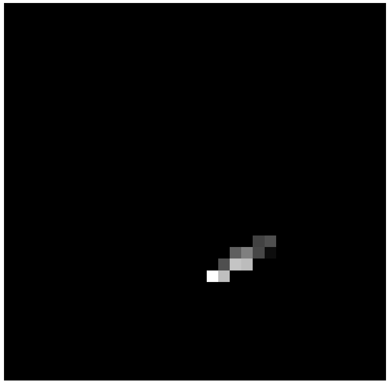
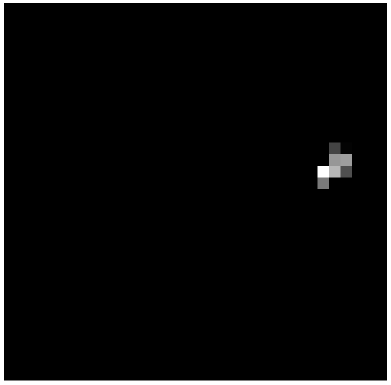
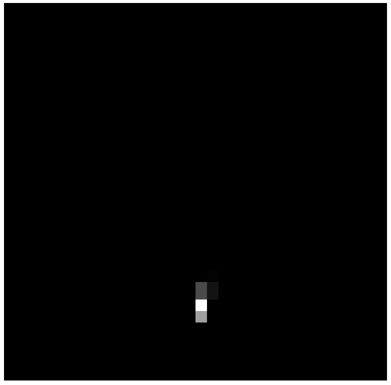


# Generated images: raw output

Gamma images:

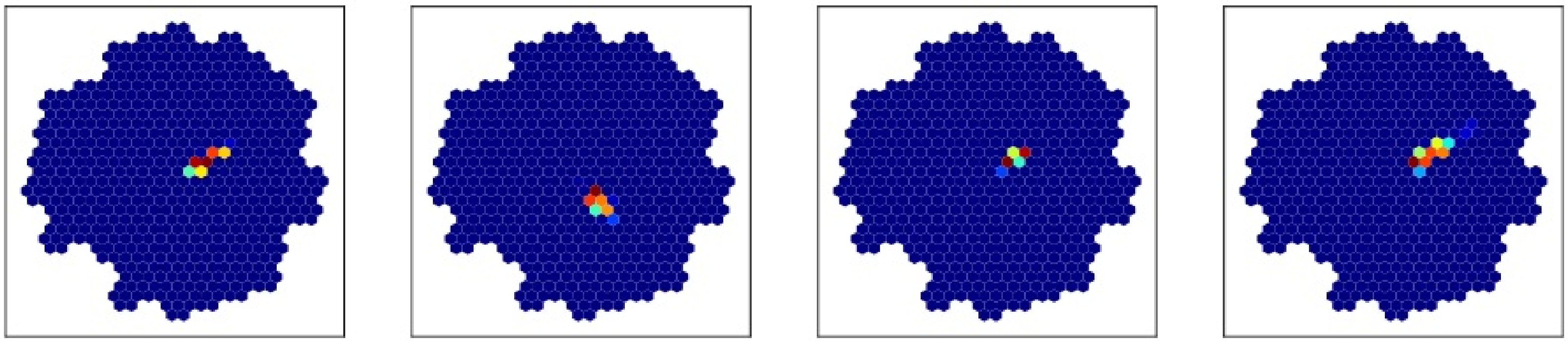





Proton images:

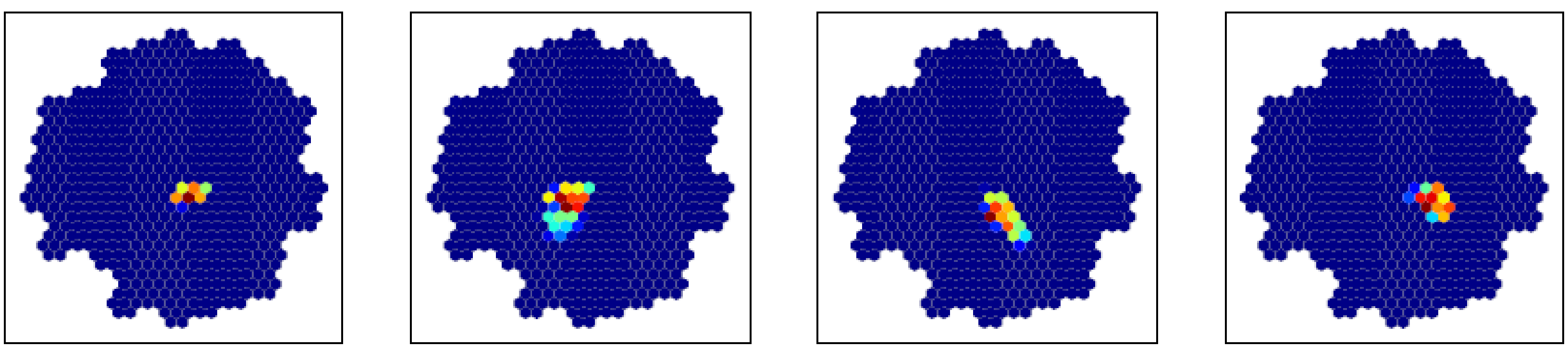





# Generated images converted back to the hexagonal form

Gamma images:



Proton images:



# Image generation: numerical performance indicators

Network training at the GPU Tesla P100 took about 20 hours for each network.

After training, generation of 4000 events (of any type) takes about 10 seconds.

Testing the results using third-party software showed that more than 95% of the generated images were found to be correct.

# Conclusion

Generative adversarial networks simulate proton and gamma events for the TAIGA experiment with a high degree of accuracy and reliability.

Most of the generated events are indistinguishable from the events generated using the traditional Monte Carlo method.

At the same time, the rate of generation of events using GAN networks is more than 1000 times higher than the rate of generation by the Monte Carlo method.

Thank you for attention!