Architecture of a generative adversarial network and preparation of input data for modeling gamma event images for the TAIGA-IACT experiment

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Air showers and event images

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.

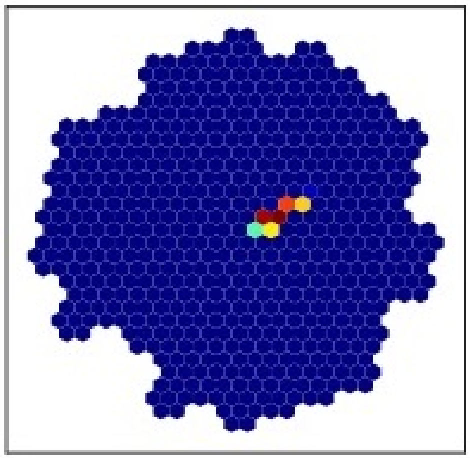
Detected data form "images" of the air shower.

Types of events observed

- gamma-quanta — events of interest

- hadrons - background events
  - most of the observed hadronic events are proton events

Identifying the type of event



gamma event

?

proton event

To ensure correct gamma event/proton event separation a large amount of experimental data, including simulated data, is required. And this data should contain a lot of events of both types.

Task and goal setting

Current situation:

Images of 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!

Our goal: simulate images of gamma events quickly and still accurately

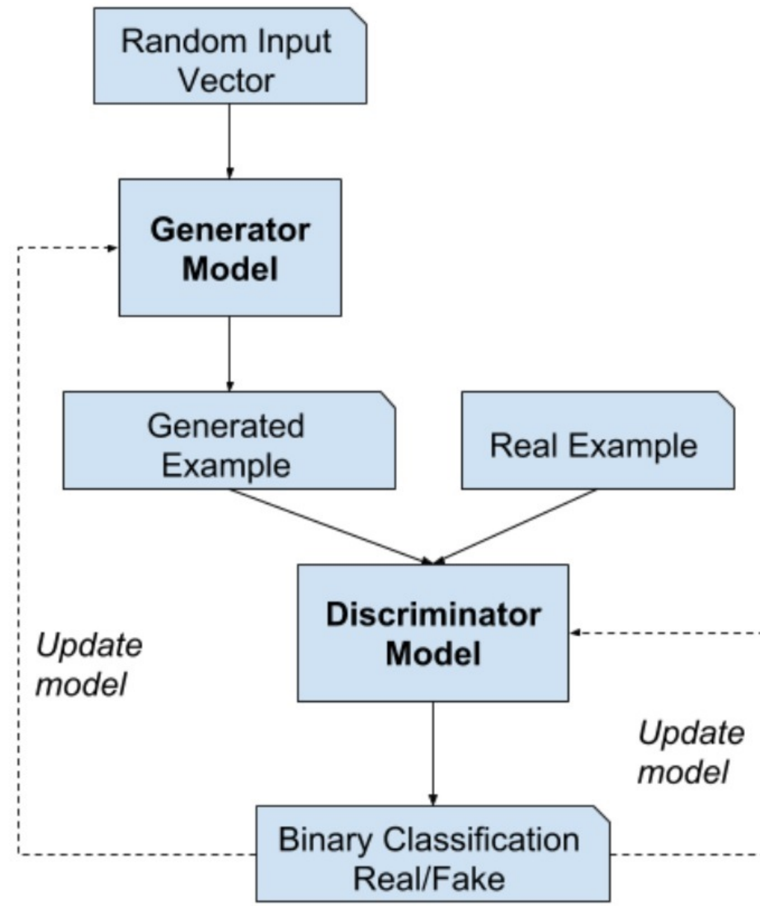
Generative adversarial network (GAN)

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.



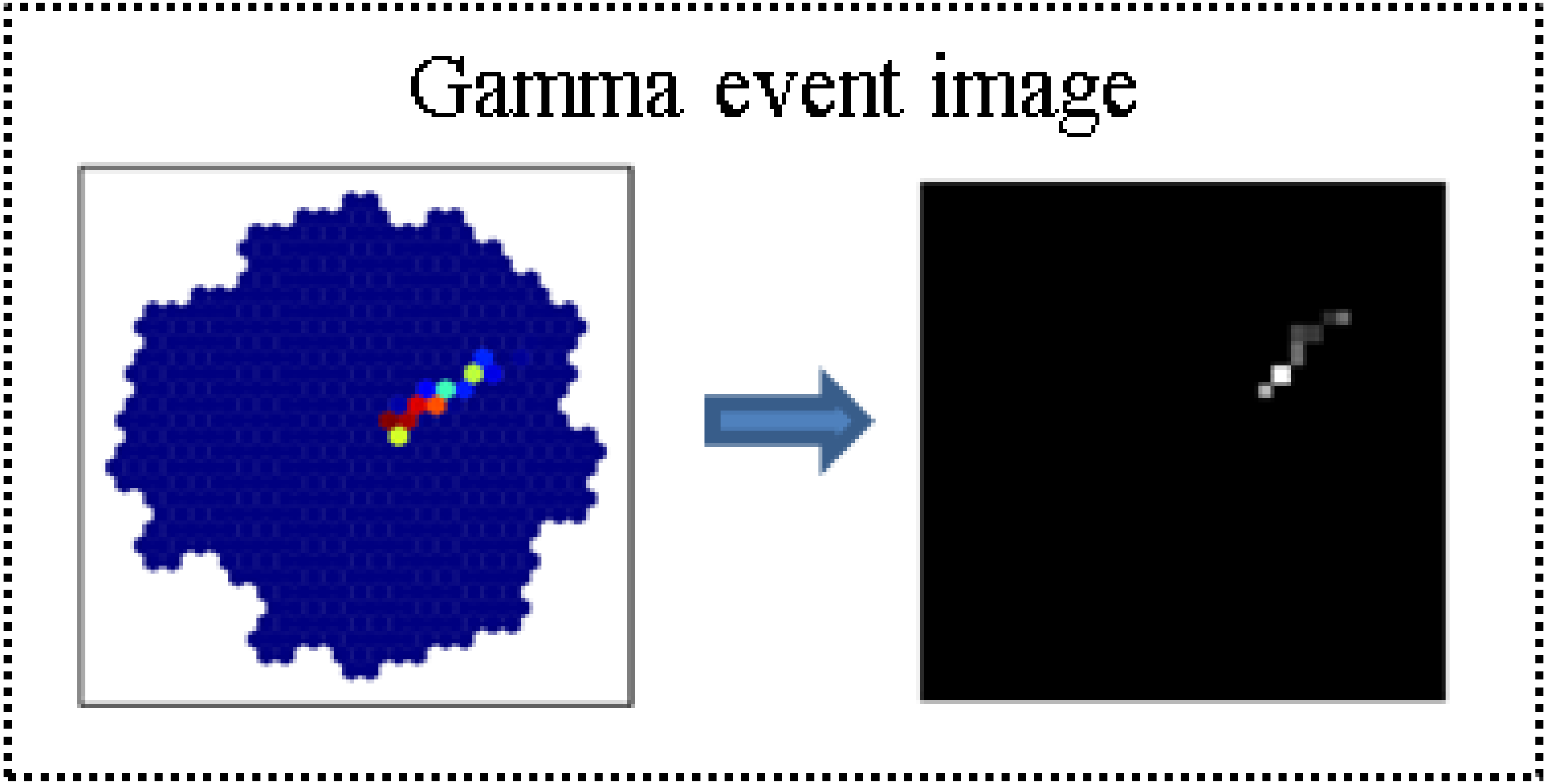
Training dataset preparation

As a training set we took a sample of two-dimensional gamma images obtained using TAIGA Monte Carlo simulation software, containing about 25,000 gamma events.

The original hexagonal images 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 contains images 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).

Image conversion example



Improving quality of generation

The images of the gamma of events have elliptical shape. When observing gamma events, the telescope is pointing towards the source of gamma quanta, that’s why the recorded ellipses should be pointed towards the center of the picture.

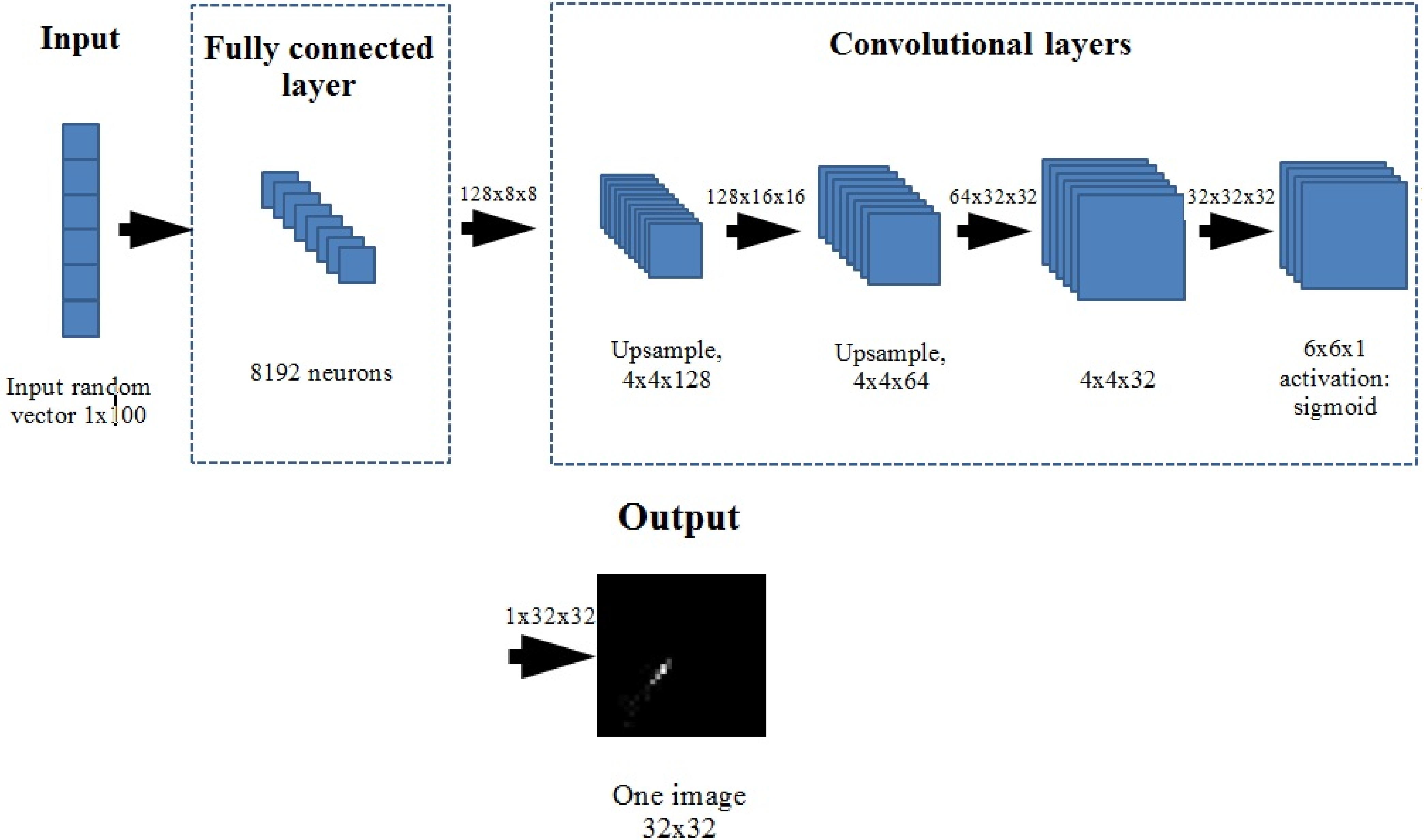
This means that our network must learn the rotational symmetry of images - ellipses can come from different directions, but all must be directed to the center.

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

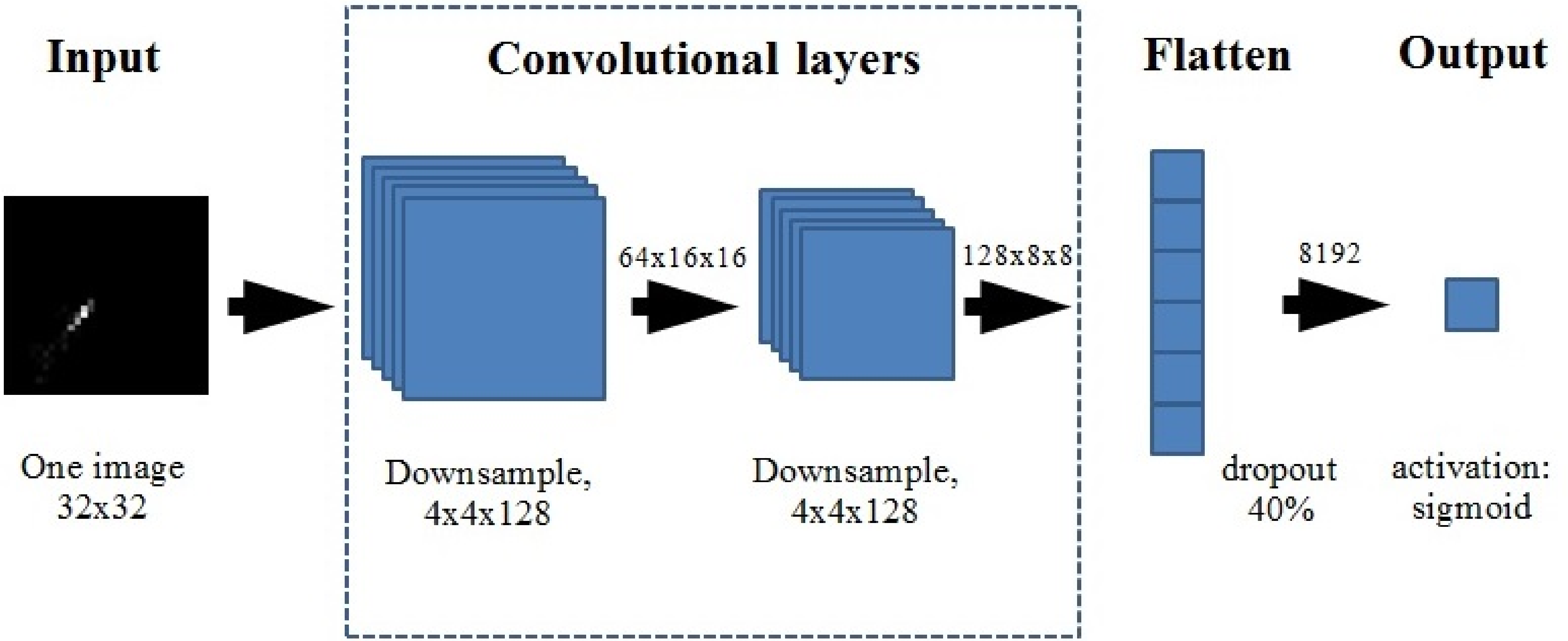
This increased the sample size by 6 times, respectively increasing the training time. But on the other hand, the quality of generating gamma images has improved significantly.

About 5% of the generated gamma images, which were previously highly likely to be recognized as protons, became highly likely to be recognized as gamma.

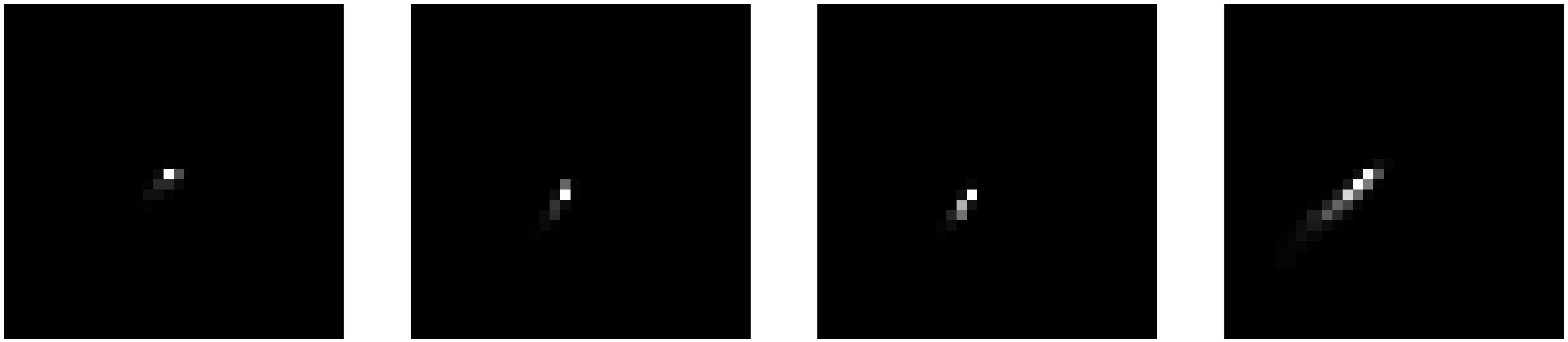
Generator architecture



Discriminator architecture



Generated gamma images: network output



Every generated image can be easily converted back to hexagonal form:

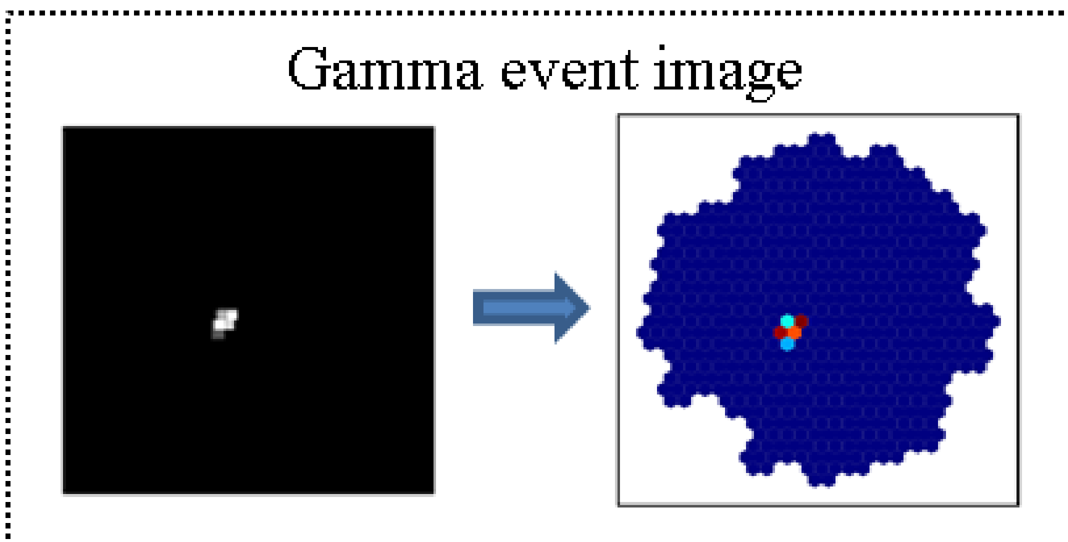
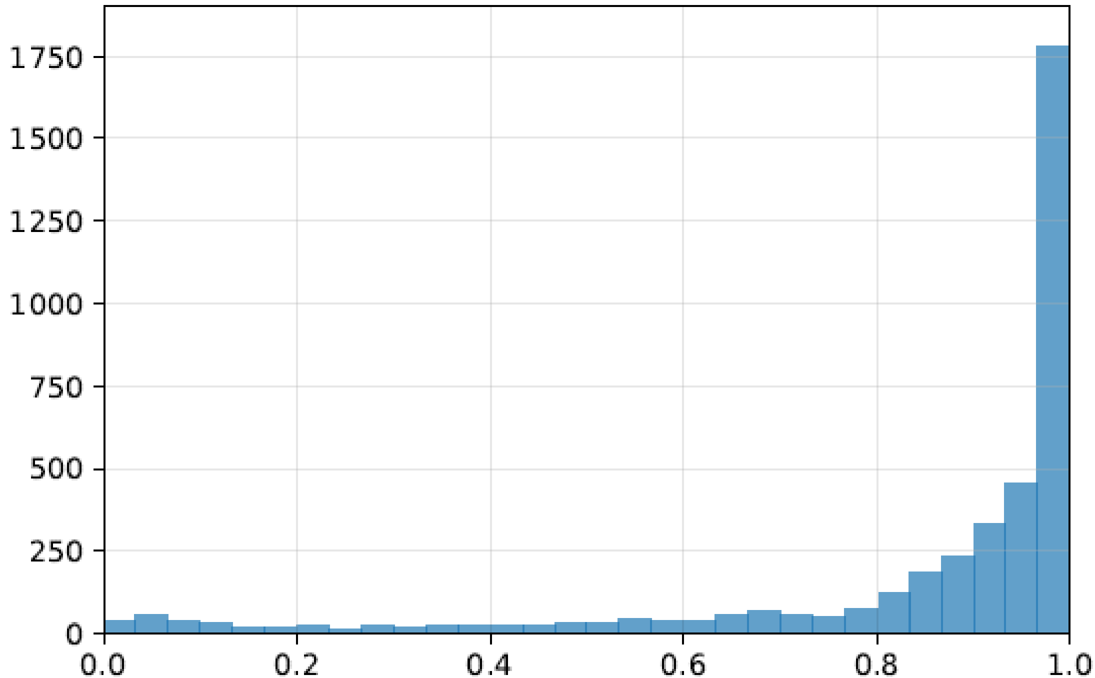


Image generation detais and results verification

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

After training, the network is able to generate about 400 event images in a second.

Testing the results using third-party software showed that more than 90% of the generated images were found to be very good, another 5% were acceptable.



The X-axis in the plot represents the probability that the image is a gamma event and the Y-axis is the number of generated gamma events classified as gamma with a given probability.

Conclusion

A generative adversarial network simulate gamma event images for the TAIGA-IACT experiment with a reasonable degree of accuracy.

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

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

Thank you for attention!