# Search for photon-induced air showers at the Carpet-3 experiment

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## Abstract

*We report our results on the new technique for searching for photon-induced EAS events at the Carpet-3 experiment. To search for photon-like events, we employ a neural network, trained on Monte-Carlo simulations of the experiment. Both reconstructed EAS parameters and raw detector signal data are being used. On Monte-Carlo simulations our method achieves considerably higher background rejection efficiency than traditional methods, particularly for EAS events with high muon content.*

## 1. Introduction

In recent years, there has been a significant interest in high-energy gamma rays. Setting limits on ultra-high energy photon flux has a big importance for experimental constraints on physics beyond the Standard Model and models of evolution of astrophysical objects which produce those photons. Experimental evidence, such as the recent GRB221009A event, indicates that there exists some mechanism that allows the propagation of ultra-high energy photons through the Universe (for example [1]), avoiding the energy loss by pair production on the cosmic microwave background. This motivates our search for high energy photons at the Carpet-3 experiment. In practice, identifying photon-induced showers in an overwhelming background of hadron events is not an easy task. We employ a custom neural network to improve the existing photon detection algorithm, which is based on the showers muon content.

## 2. Carpet-3 experiment and data

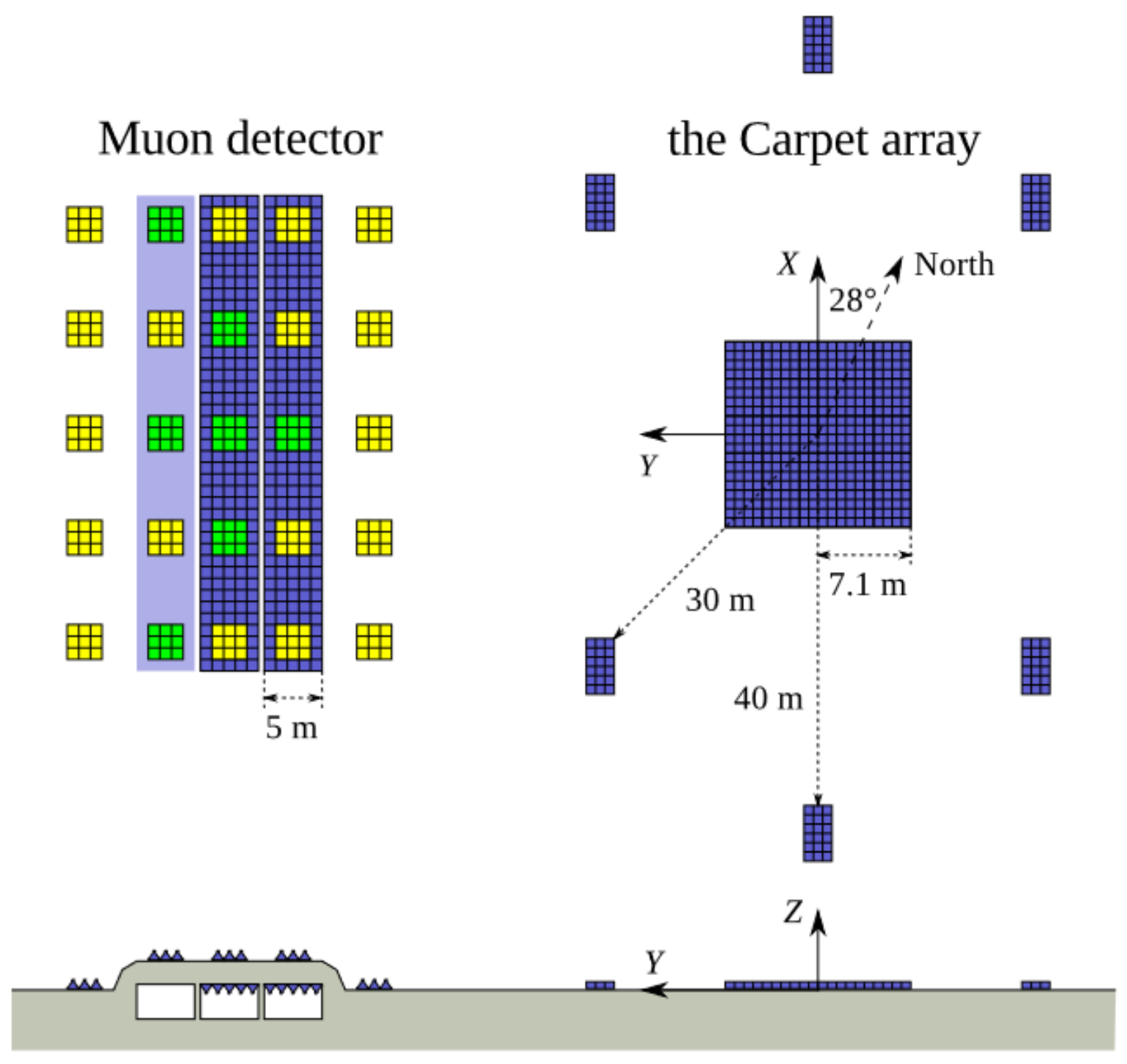

**Figure 1:** *Carpet-3 scheme. As of now, the surface detectors above the muon detector are not active in the present configuration, and their existence is ignored here.*

Carpet-3 [2] is a surface air shower detector array located in Baksan Valley containing a continuous 200 $m^2$ central detector, which consists of 400 individual scintillation detectors and a separate muon detector, which is located underground and is used to estimate the muon content of the shower. The experiment provides direct integral signals from the detectors as well as a number of reconstructed shower parameters, such as the primary energy, shower size $N_e$, and others. This work is based on Monte-Carlo simulations of air showers, done with the CORSIKA package and a dedicated MC code [3] for simulating the installation response. The simulated events pass the same reconstruction procedure and selection criteria as the real data.

The simulated set consists of 150 000 events and 1 500 distinct air showers, split evenly between proton and photon primaries. Simulation assumes isotropic cosmic ray arrival directions. The energy spectrum was fixed to $E^{-1}$ and spans from 30 TeV to 30 PeV. After passing the quality cuts, there are 25 000 events left.

## 3. Photon/hadron discrimination

To classify the events, we use the following reconstructed parameters:

1. Raw detector signals of the central array
2. Shower axis coordinates X, Y
3. Shower size $N_e$
4. Number of muons $N_\mu$
5. Azimuthal and zenith angles $\phi, \theta$
6. Shower "clumpinnes" $P$

$P$ is defined following reference [4] as:

$$P = \sum_k \frac{2}{N_k(N_k-1)} \cdot \frac{1}{<S_k>} \sum_{i>j} (S_{ik} - S_{jk})^2 \quad (1)$$

This variable is sensitive to the azimuthal asymmetry in the shower LDF and can be used as a discriminating factor. Especially at high $N_\mu$, it allows to separate photon showers from the rest, as shown on figure 2.

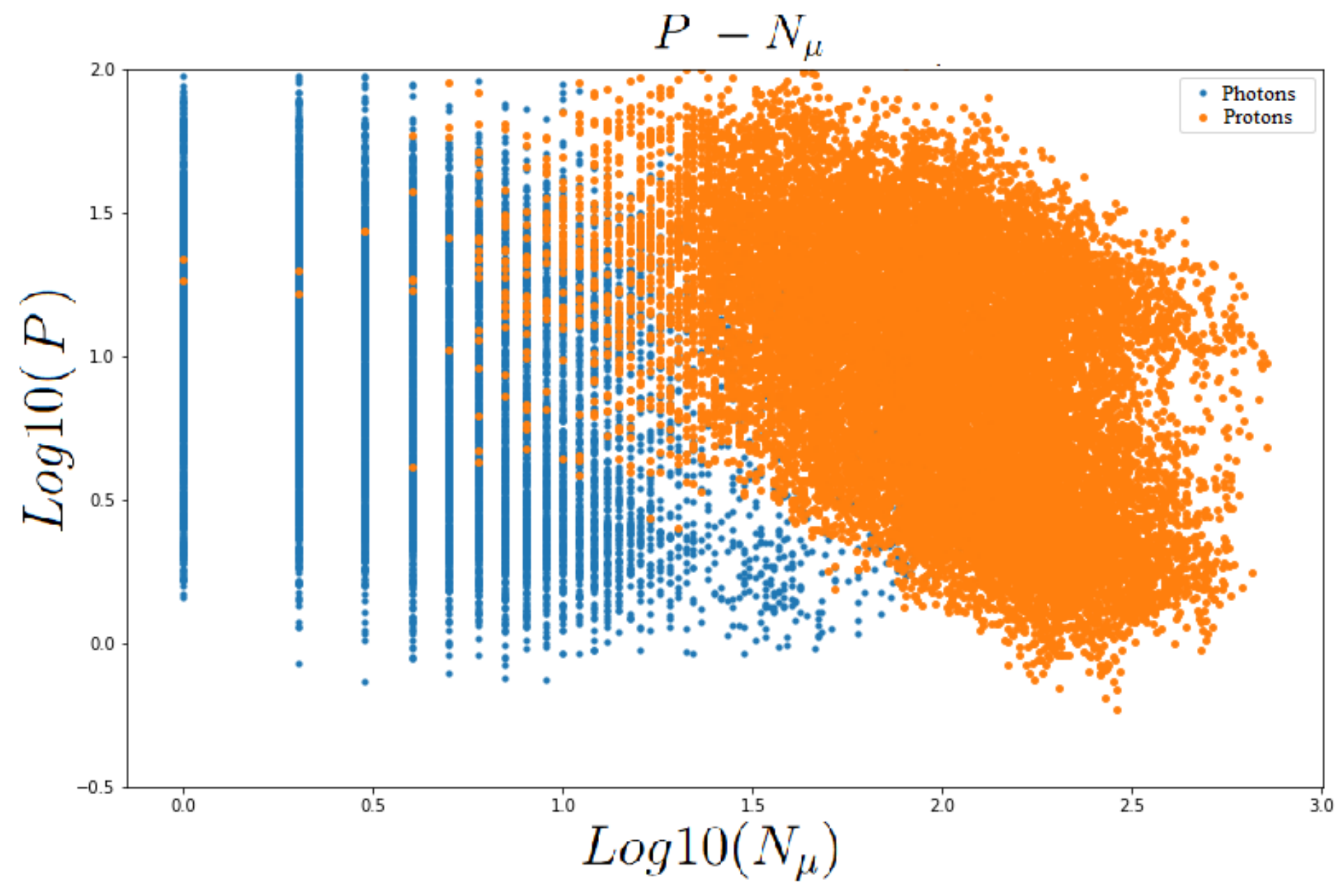

**Figure 2:** *Scatter plot of the shower "clumpinnes" vs the number of muons. The separation of photons and hadrons is evident.*

## 4. Neural network classifier

We train a hybrid neural network on the MC dataset. Taking advantage of the spatial structure, raw detector data is fed to a convolutional neural network, while other parameters are processed by a fully-connected part. The architecture is shown in figure 3. Further analysis shows that the most important reconstructed parameters apart from the number of muons are the "clumpinnes" P and the shower size $N_e$. The network performs significantly better when using the raw detector data, showing that the LDF indeed carries a lot of information about the primary particle.

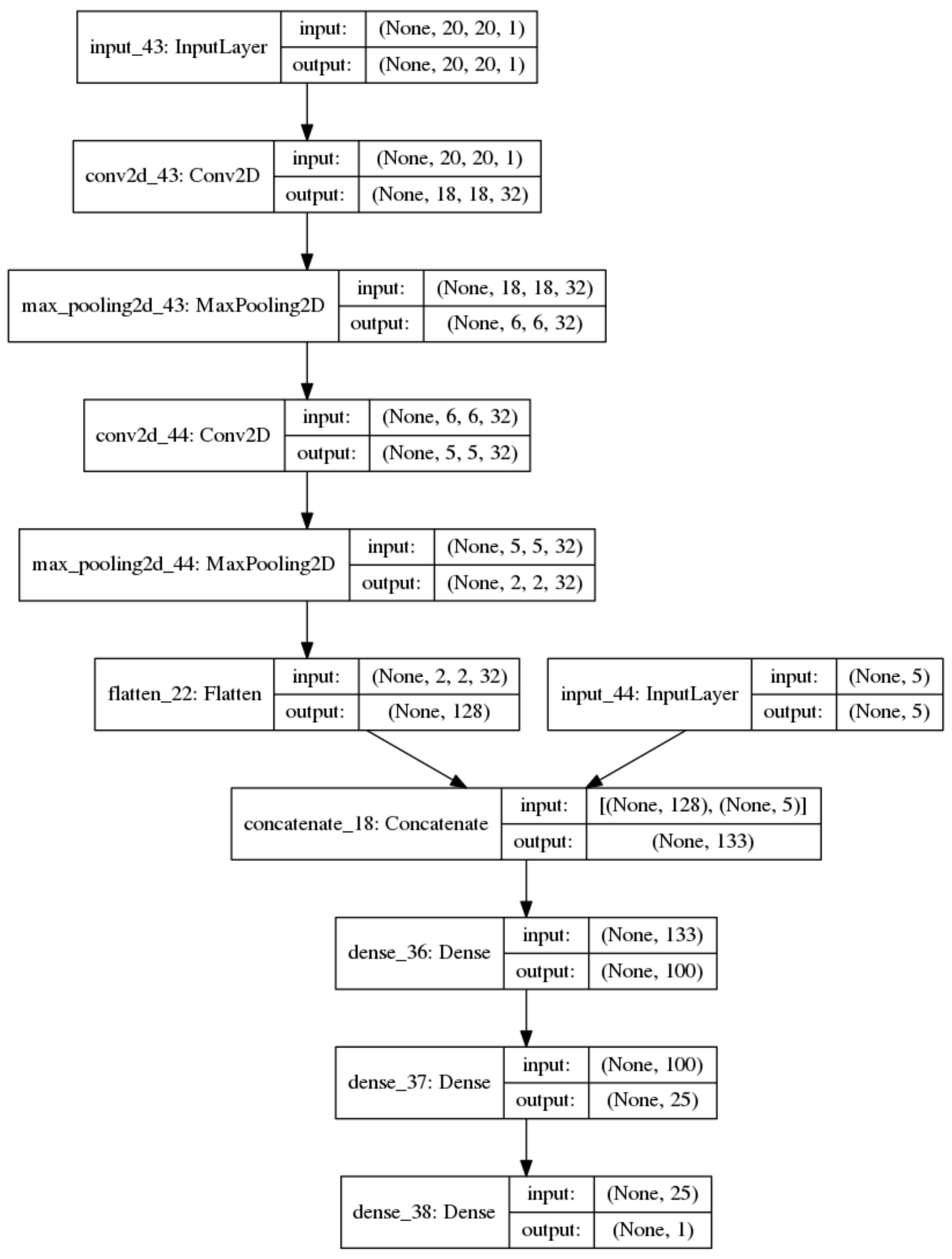

**Figure 3:** *Neural network architecture.*

On the test set, our network achieves a significantly higher background rejection factor that a method using only the reconstructed parameters. It reaches $10^{-4}$ background rejection with a selection efficiency of 80%.

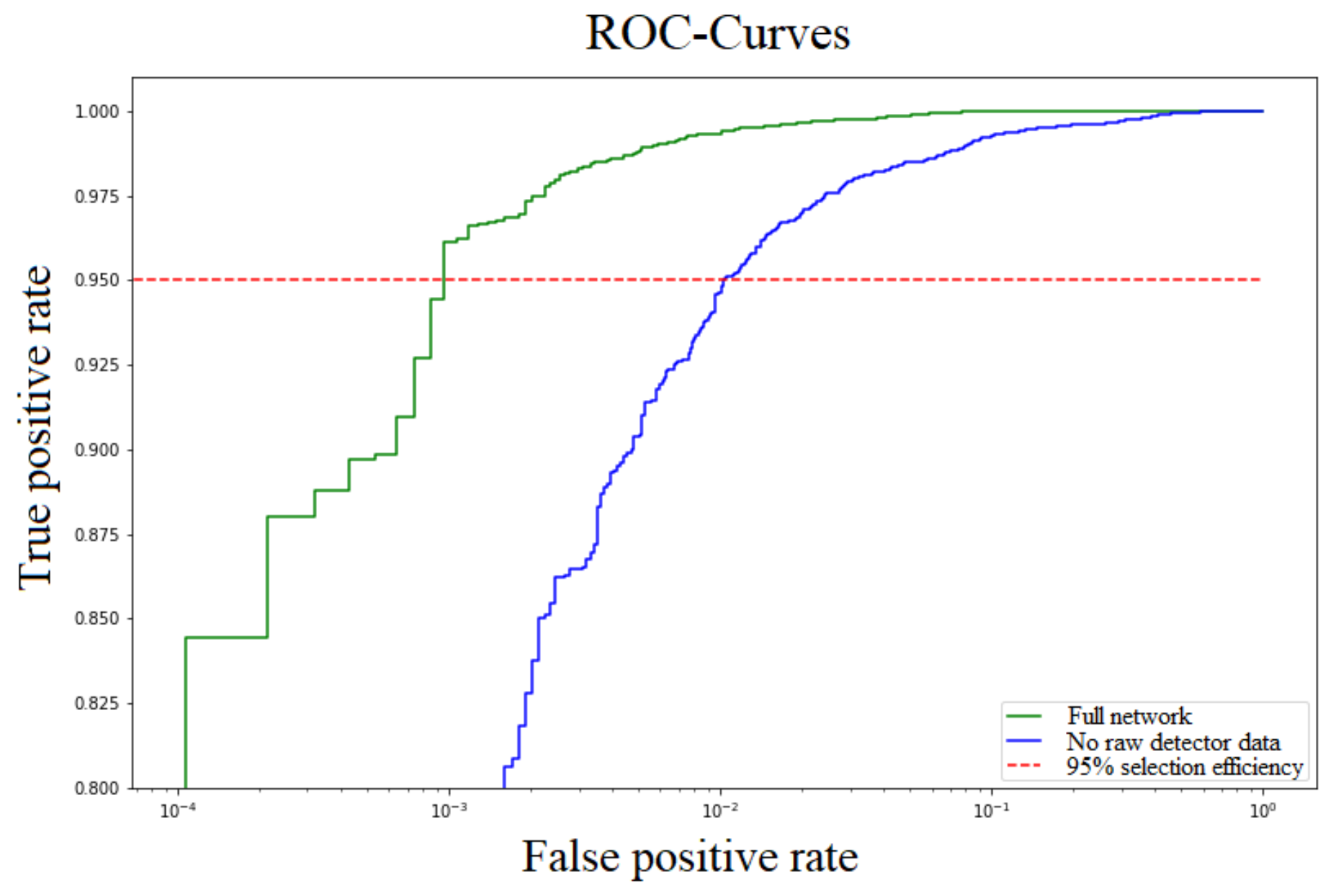

**Figure 4:** *ROC-curves for the full neural network (in green) and for a network using only the reconstructed parameters (in blue). Currently used algorithm on the experiment uses only the number of muons, and so is worse than both cases above.*

## 5. Conclusion

We have developed a neural network capable of discriminating the gamma/hadron showers with improved efficiency. It efficiently uses both the raw detector data and reconstructed shower parameters. In the future, it can be used to acquire new constraints on the photon flux.

## References

[1] Troitsky S., JCAP 01 (2024) 016, arXiv:2307.08313

[2] Szabelski, J. Nuclear Physics B Proceedings Supplements 196, 371–374 arXiv:0902.0252 (2009).

[3] Dzhappuev, D. D., Dzaparova, I. M., Gorbacheva, E. A., et al. JETP Letters 109(4), 226–231 February (2019).

[4] R. Conceição et al., Journal of Cosmology and Astroparticle Physics (2022).