Performance of convolutional neural networks processing simulated IACT images in the TAIGA experiment

Stanislav Polyakov, Alexander Kryukov, Evgeny Postnikov
Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University

Extensive air showers created by high-energy particles interacting with the Earth atmosphere can be detected using imaging atmospheric Cherenkov telescopes (IACTs). The IACT images can be analyzed to distinguish between the events caused by gamma rays and by hadrons and to infer the parameters of the event such as the energy of the primary particle.

We use convolutional neural networks to classify the events and estimate the energy of the original gamma ray.

Event sets

We used two sets of events generated by Monte Carlo algorithm for TAIGA IACTs:

- s1: 3400 gamma events and 9306 hadron (proton) events, detected by two telescopes positioned at a varying distance between 300 and 350 metres from each other, original particle energy from 1 to 45 TeV;
- s2: 18359 gamma events (no hadron events), detected by two telescopes positioned at 324 metres from each other, original particle energy from 1 to 50 TeV.

Training and test sets

We trained similar neural networks (with minimal necessary modifications) on data from both telescopes and from a first telescope only.

Training sets consisted of 80% of the corresponding set and the remaining 20% were used as test sets. The results (the number of correctly classified and misclassified particles and average relative error of energy estimate) were averaged over 10 iterations.

Classification neural network architecture

Input: 30x31x2
Conv2D 5x5, W
AvgPool 2x2
Conv2D 5x5, W
AvgPool 2x2
Conv2D 3x3, W
AvgPool 2x2
Flatten 3x3xW → 9xW
Fully connected layer, 3xW
Fully connected layer, W
Output layer, 2

W is a variable parameter

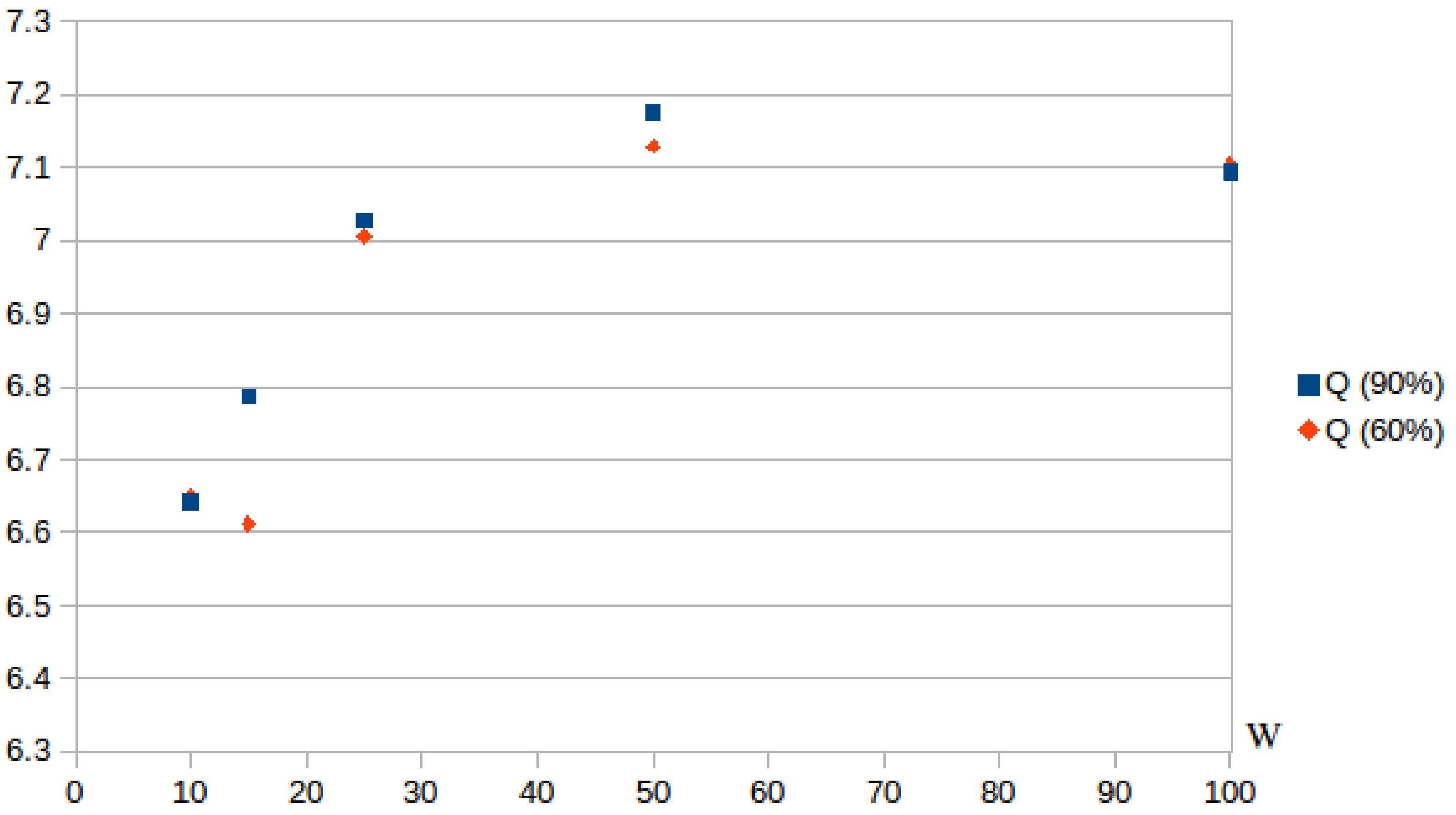
Quality factor *Q*

As the measure of quality of particle identification we estimated a selection quality factor *Q*, which indicates an improvement of a significance of the statistical hypothesis that the events do not belong to the background in comparison with the significance before selection. For Poisson distribution

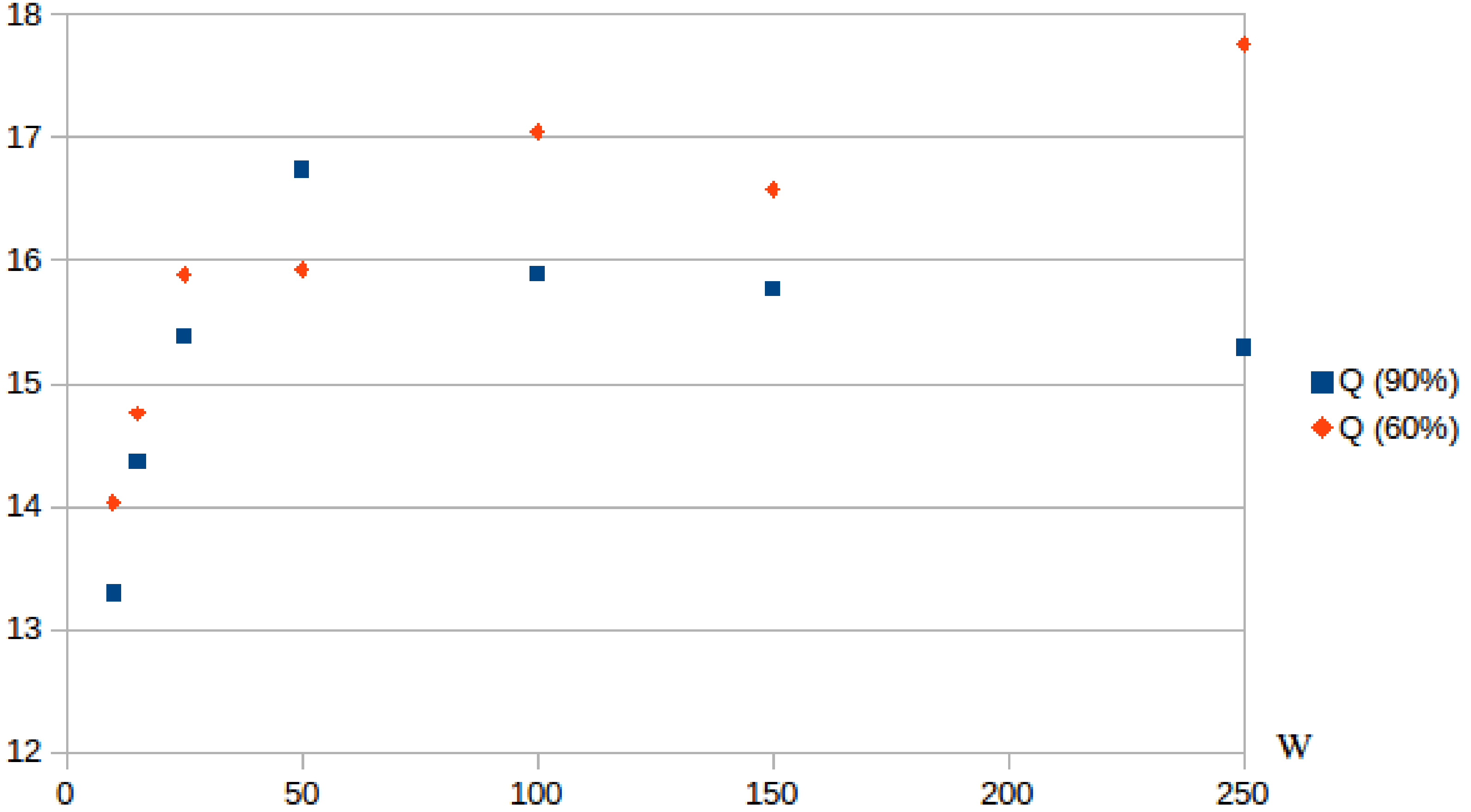
$$Q = \frac{\Gamma_{true}/\Gamma}{\Gamma_{false}/H}$$

where Γ and *H* are the total number of gamma events and hadron events, respectively, Γ_{true} and Γ_{false} are the number of events correctly and incorrectly identified as gamma events.

Classification quality in monoscopic mode



Classification quality in stereoscopic mode



A neural network for energy estimation: architecture example

Input: 30x31x2x2
Conv2D 5x5, 12
AvgPool 2x2
Conv2D 5x5, 25
AvgPool 2x2
Conv2D 3x3, 25
AvgPool 2x2
Flatten 3x3x25 $\rightarrow$ 225
Fully connected, 50
Fully connected, 50
Fully connected, 50
Output 1

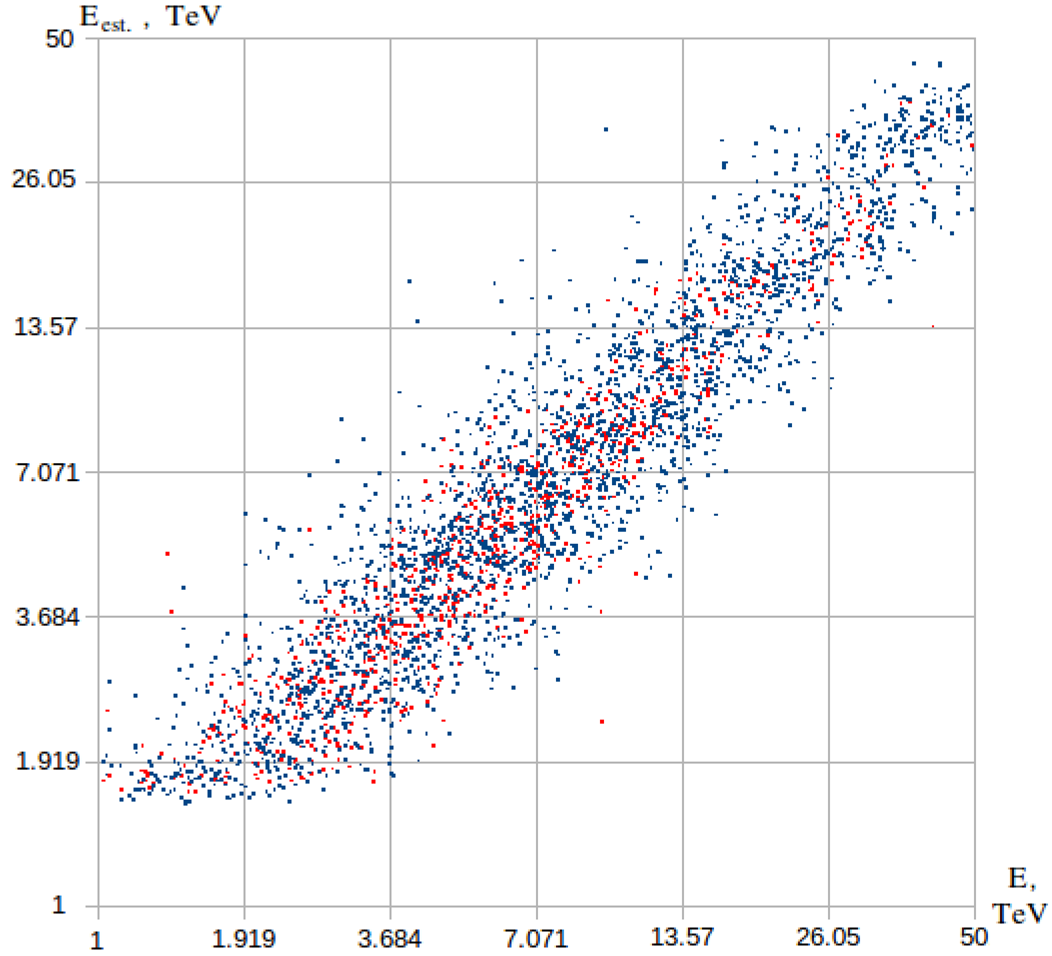
Energy estimates for s1 and s2

In monoscopic mode, the most accurate neural networks have 20.8% average relative error for energy estimates for the set s1 and 24.0% for the set s2.

In stereoscopic mode, the most accurate neural networks have 15.5% average relative error for the set s1 and 12.5% for the set s2.

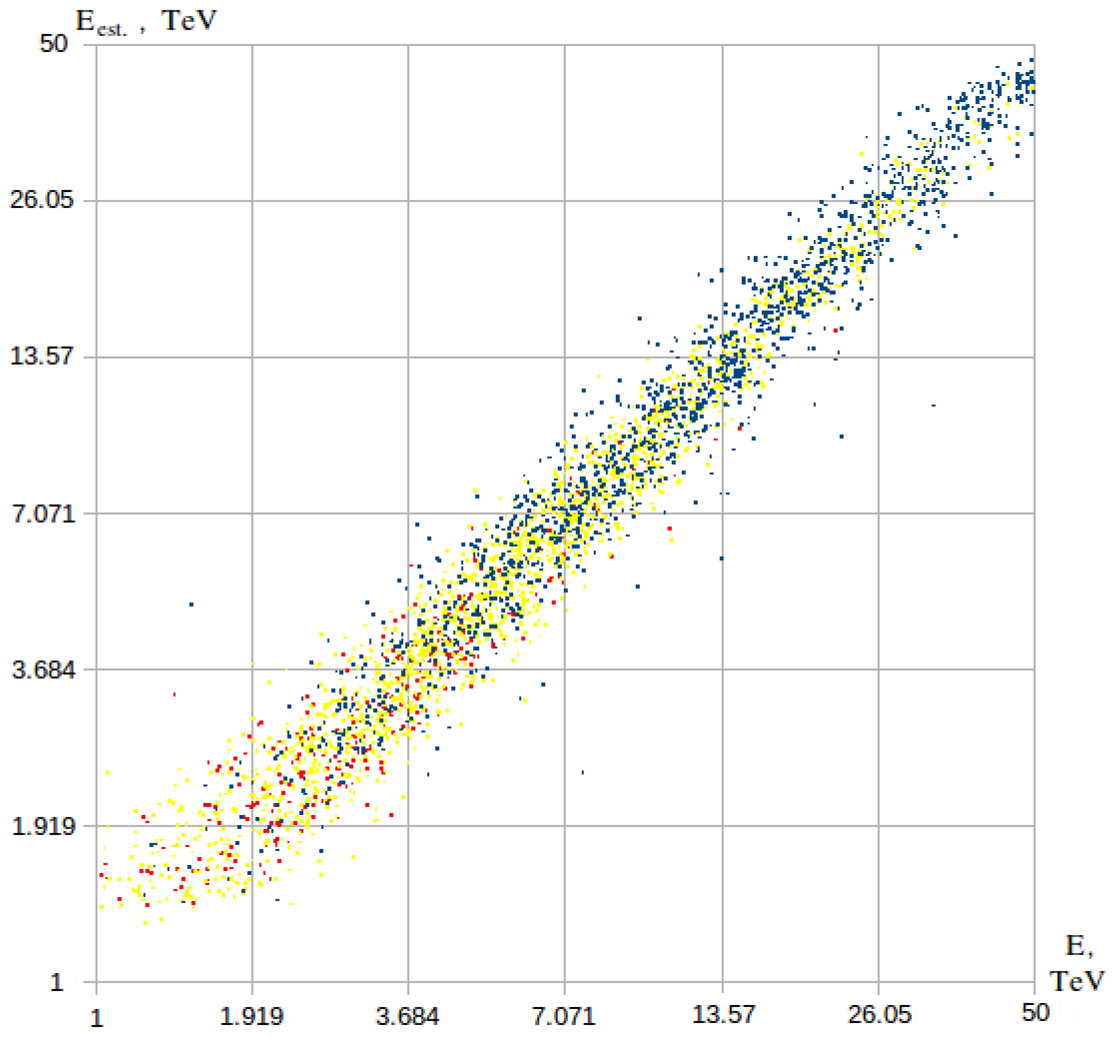
Monoscopic energy estimates

Each dot corresponds to an event; red dots are the events with weighted center of the image <1° from the center of the telescope.



Stereoscopic energy estimates

Each dot corresponds to an event; blue dots are the events with weighted centers of each image >1° from the center of the telescope; red dots are the events with weighted centers of each image <1° from the center of the telescope.



Results

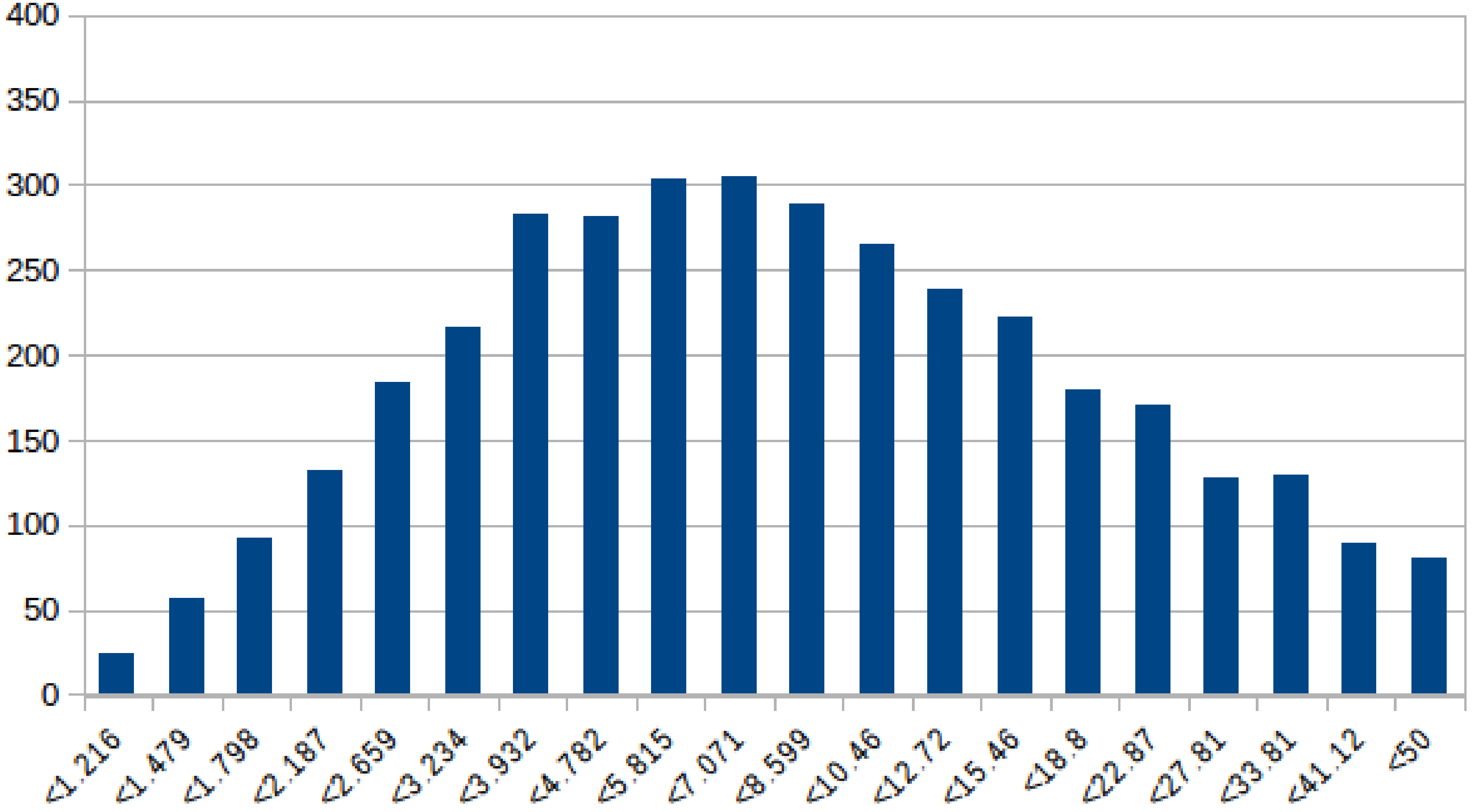
We trained convolutional neural networks to identify gamma rays and estimate their energy based on images from IACTs of the TAIGA expetiment. Our results demonstrate that adding an image from a second telescope improves the quality of original particle classification (with *Q* increasing from 7 to 16-17) and the accuracy of its energy estimates (with average relative error decreasing from 20.8% and 24.0% to 15.5% and 12.5%, respectively).

Appendix A: classification results (best case)

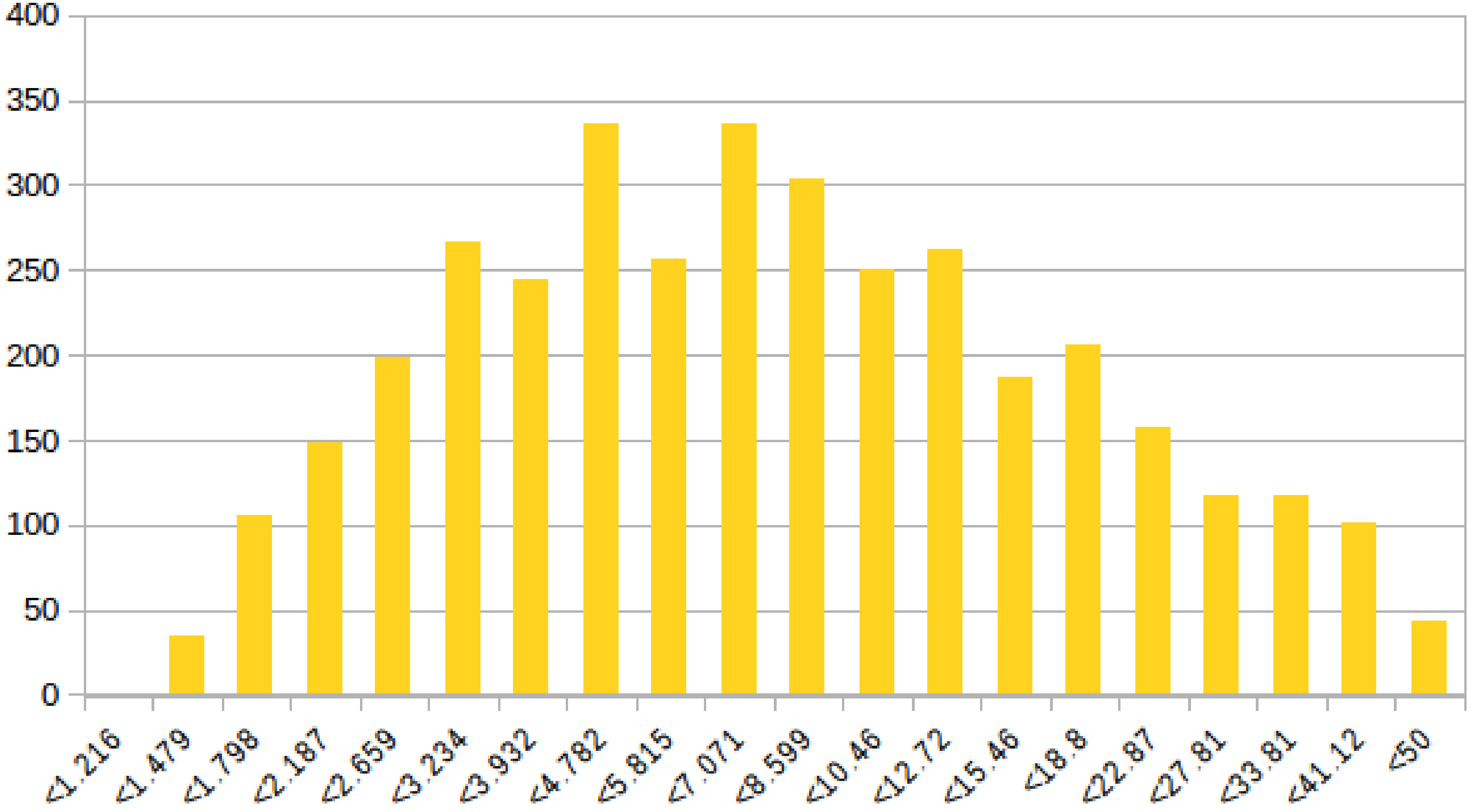
Total gamma events: 6919
Total hadron events: 18491
Correctly identified gamma events: 4041 (58.4%)
Misclassified proton events: 19 (0.1%)

Q = 17.8

Appendix B: energy histogram (s2, test set)



Appendix B: energy estimates histogram (s2, test set, stereoscopic mode)



Appendix B: energy estimates histogram (s2, test set, monoscopic mode)