

Definition of the muon CREDO events with the PC web camera

T. Wibig

*Wydział Fizyki i Informatyki Stosowanej,
Uniwersytet Łódzki, ul. Pomorska 149/153, 90-236 Łódź;
Narodowe Centrum Bada Jądrowych, Zakład Astrofizyki,
ul. 28 Pułku Strzelców Kaniowskich 69, 90-558 Łódź.*

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Abstract

The events registered by the CREDO detectors are expected to be traces of high energy (minimum ionizing) particles passing the matrix of the covered iPhone camera. The fluctuations in the dark frames, however, could mimic the sought signs. We discuss the method to separate muon events from this ‘noise’. For the present work we used the PC web camera instead of the iPhone of the original CREDO Project and obtained results have to be confirmed by the further studies. We propose some way of discrimination of suspected muon events, but it should be stressed that we do not have proof (yet) that the selected events are indeed traces of cosmic ray particle.

I. INTRODUCTION

Events registered by the iPhone camera with the lens covered are mostly black frames. In the CREDO experiment we wish to look at these mostly black frames looking for the tiny flash of ‘light’ produced by the cosmic ray particles passing the camera CCD matrix. The frames on first sight completely empty are, when inspected closely with the high ‘amplification’ are full of noise, what is quite natural. The noise has mostly the thermodynamical origin, so if one has a time to wait for the arbitrary big fluctuation it will be seen (in a reasonable limit - probability falls $\sim$ exponentially). On the other hand, charged particle originated in the cosmic ray cascades developing in the atmosphere, having the energy high enough to be the minimum ionizing particle (more than about 1 GeV) is losing about 5 keV of its energy to ionizing an active layer of CCD matrix. This is the energy of ~ 1000 optical photons what obviously should give the pronounced ‘point like’ signal on the dark frame. Due to the construction of the CCD/CMOS matrix (and the signal processing which transform the charge deposit in each pixel to the value stored in the camera memory) the ionization losses are spread to the neighboring pixels of the image and the expected muon trace (which form mostly the high energy particle flux at the Earth surface) is extended and its size depends on the camera details.

Taking into account that the typical size of the CCD matrix of order of 10 square millimeters and the muon flux on a sea level is roughly 10^{-4} muons per square millimeter per second gives, one can expect the rate of muons passing the camera of about few per hour. This of course should be diminished at first by the fill factor which could be of order of 30% (plus additional $\sim 10\%$ for the edge cuts) but also by the CREDO detector death time. This time depends again on the camera type and it is hard to determine without the deep and detailed knowledge. It seems reasonable to put the limit for the single muon registration rate to be less than 1 per hour, few per day.

II. REGISTRATION

This work was done with the images obtained not by the iPhones, as it is in the original CREDO Project, but with the PC web camera. The stream of frames is transmitted to the PC by the USB port with the rate of few Hz. Program which allows us to manipulate

with such data is the modification of the programs of Marek Knap available in the CREDO internal pages.

The frames continuously received from the camera, are mostly empty, noised frames, which are not interested by definition. We wish, however, to see something ‘unexpected’, something suspected to be the trace of the charged particle, some sign of a potential interest in this see of ‘nothing’. To look for such events *the first level trigger* should be defined. It ought to be fired when such ‘suspected cases’ appears and it should trigger the action of the registration of the given frame. The triggered events are stored for further examinations. The first level trigger should be fast and easy. It should reduced the stream of frames to the reasonable limit which, taking into account the estimated above moun rate, could be of order 100 per hour. The obvious proposition is to search for the points which exceeded the ‘nothing’ by a certain level.

To make this more exact it is necessary to determined the *average dark frame* taken with the same condition as assumed for the planned measurement. To read out of few thousands dark frames does not take long and makes no problem. Using them we memorize the average value of the signal $A_{i,j}$ and its dispersion $D_{i,j}$ for each camera pixel. There is no reason to keep separately the information for all colour channels. We tested this assumption and no evidence of the unusual performance of the images related to the specific colour was found. We will therefor sum all channels together and work hereafter with this sums. With the matrix $A_{i,j}$ we can determine the overall average ‘dark signal’ $\langle A \rangle$ and overall average dispersion $\langle D \rangle$. If the matrix is relatively uniform they have some meaning, but in the case where there are visible big spacial changes of the camera response the meaning is rather questionable and these parameters should be taken with care. But anyway, those values can help to determine pixels which do not work properly: the ‘hot’ or ‘blind’ pixels. Comparing the particular pixel average signal $A_{i,j}$ with $\langle A \rangle$ within the limit of some multiple of $\langle D \rangle$ marks the ‘wrong pixels’ which will be excluded from the analysis later on.

The example of the average dark frame is given in Fig. 1

The simple first level trigger we used in the present work is obtained by comparing actual signal in the pixel (i, j) : $S_{i,j}$ with the noise $A_{i,j}$ increased by a constant factor multiply of this pixel noise dispersion $D_{i,j}$. Because we are working on big number of pixels (in our case it is 640×480) and the wanted reduction factor of about $\sim 1/100$ this constant (with the assumption of the Gaussian noise distribution) should be of order of 10. Its actual value

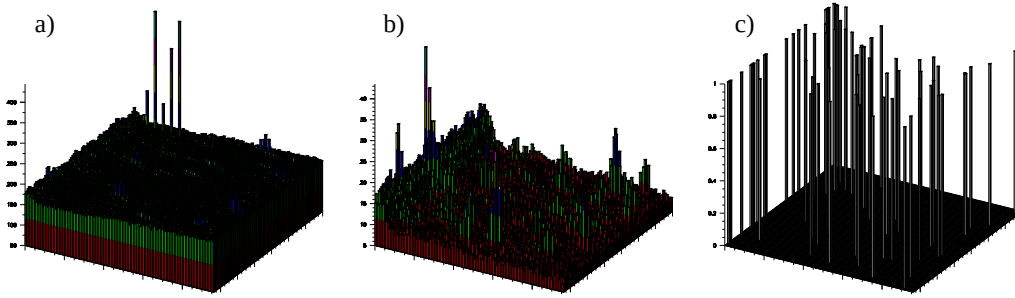


FIG. 1. Camera matrix average dark frame (a part of it): average noise signal $A_{i,j}$ a), the dispersion of noise signal $D_{i,j}$ b), and the ‘wrong pixels’ c)

can be adjusted even when the registration is going on. This makes no significant difference when we are interested in ‘unusual events’ because 100 events per hour is still the rate which secure not to lose interesting muon events.

III. ANALYSIS

The first level trigger events are stored in the computer were then they are examined to find between them the desirable cosmic ray mouns.

Examples of our typical registrations are shown in Fig. 2. In principle they could be taken as moun cases: some bright signals are seen, but of course they are not mouns. The rate of this kind of event is around 100/hour, so they represent, from the CREDO point of view, uninteresting noise, the background, which should be excluded.

The conventional wisdom is that muons should produce bright and big spot. We define few measures of the “brightness and spacial extension” of the moun image. The brightness is easy to test. As the first measure we took the maximum value of the scaled signal of all (excluding ‘wrong’) pixels in a inner part of the matrix. We cut the matrix by 20 pixels from the edges for safe, according to Fig. 1.

$$\text{brightness}_1 = \max((S_{i,j} - A_{i,j})/D_{i,j}) \quad (1)$$

To be sure that the measure is not effected by just a single pixel we define also the measure called brightness_2 as a scaled brightness of the second of the brightest pixel.

According to the space extension of the moun trace we calculate few a little different

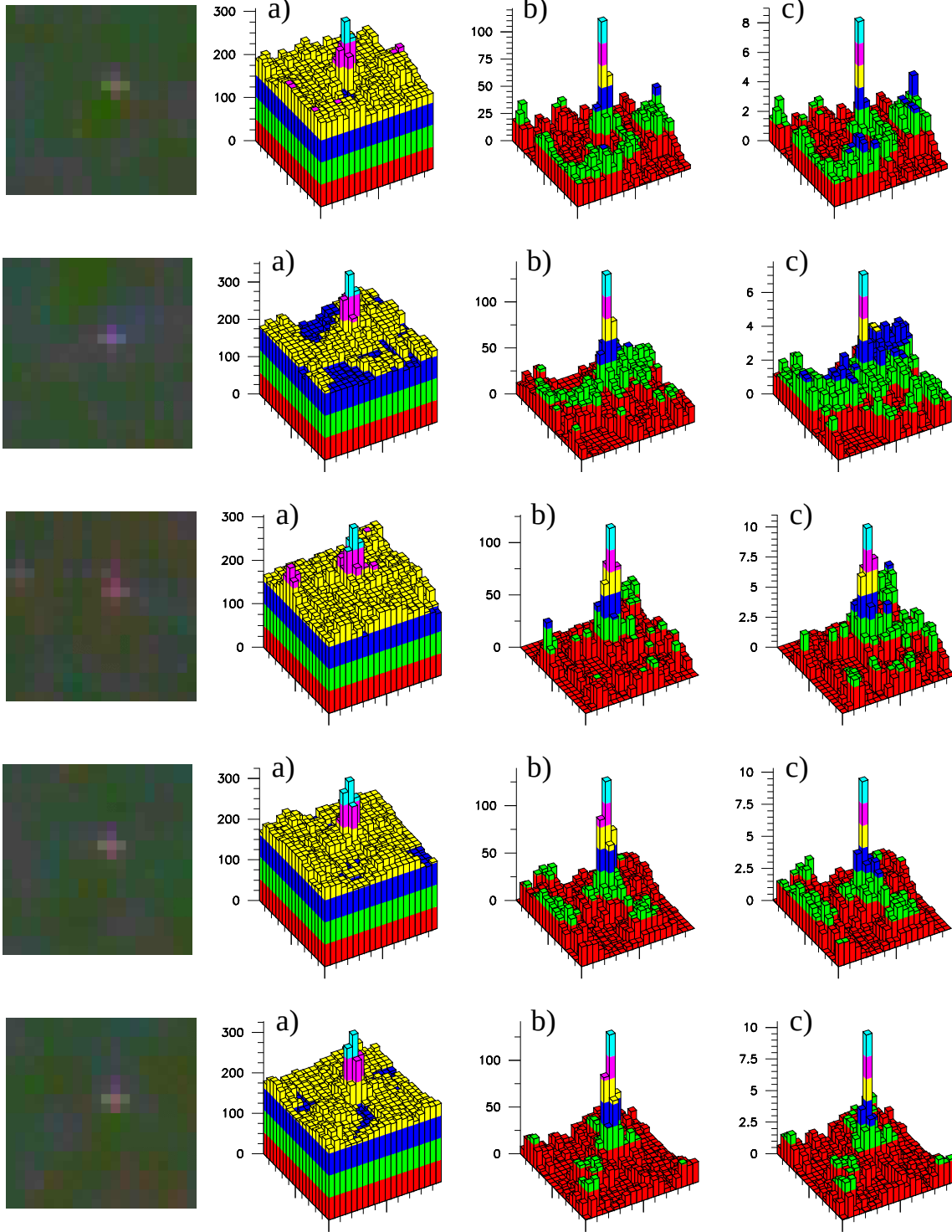


FIG. 2. Typical events registered, rather not mounds. Camera view and raw pixel contents a), difference $S_{i,j} - A_{i,j}$ b) and the difference scaled by the dispersion $(S_{i,j} - A_{i,j}) / D_{i,j}$ c).

measures. One way is to count number of pixels surrounding the brightest pixel having the scaled signal above the limit calculated with respect to the maximum.

$$\text{size}_k = \sum H((S_{i,j} - A_{i,j})/D_{i,j} - f_k \cdot \text{brightness}_1) \quad (2)$$

where H is Heaviside step function and factor f_k was assumed to be 0.5, 0.7, and 0.8 for $k=1, 2$, and 3 defining three size measures respectively. The sum goes through the square 21×21 around the brightest pixel.

Another way of measuring the size of the spot is to count pixels with the not scaled signals higher than certain level defined by the overall dispersion of the noise signals

$$\text{size}'_k = \sum H((S_{i,j} - A_{i,j}) - f' \cdot \langle D \rangle) \quad (3)$$

this time the factor f' was used as equal to 8, 9, and 10.

The last measure we tested was the one which combine size and strength of the signal:

$$\text{magnitude} = \sum_{(S_{i,j} - A_{i,j})/D_{i,j} > f_m} (S_{i,j} - A_{i,j})/D_{i,j} \quad (4)$$

It sums up all the scaled signals higher then f_m (actually 5) within the square 5×5 around the brightest pixel. We will call this measure ‘magnitude’.

All this measures were applied for the registered events. First what was found is the obvious correlation, which is not very interesting and we will not going to discussed it here. The more important were the spectra (probability distributions) of the studied measures.

The spectra of size and brightness are shown in Fig. 3.

We performed our measurements in few conditions defined by different parameters of the camera. Shown spectra are obtained for two sets of camera parameters used. The left figures are for ‘medium’ camera brightness, while right plots are for the camera parameter set producing quite bright ‘dark frames’. Points shown in the figures will be explained later.

For the size measures we can see that there is no extra deviation from the expected exponential-like shape. To be more precisely: no big tails are seen.

Concerning the brightness measure there are interesting long tails. Extreme points relates to the events which can be called ‘very bright spots’. They will be shown in details below.

The spectra of the magnitude measure are shown in Fig. 4. The spectrum for the ‘normal’ event sample exhibits very long tail, which is by no means non-exponential. For the very

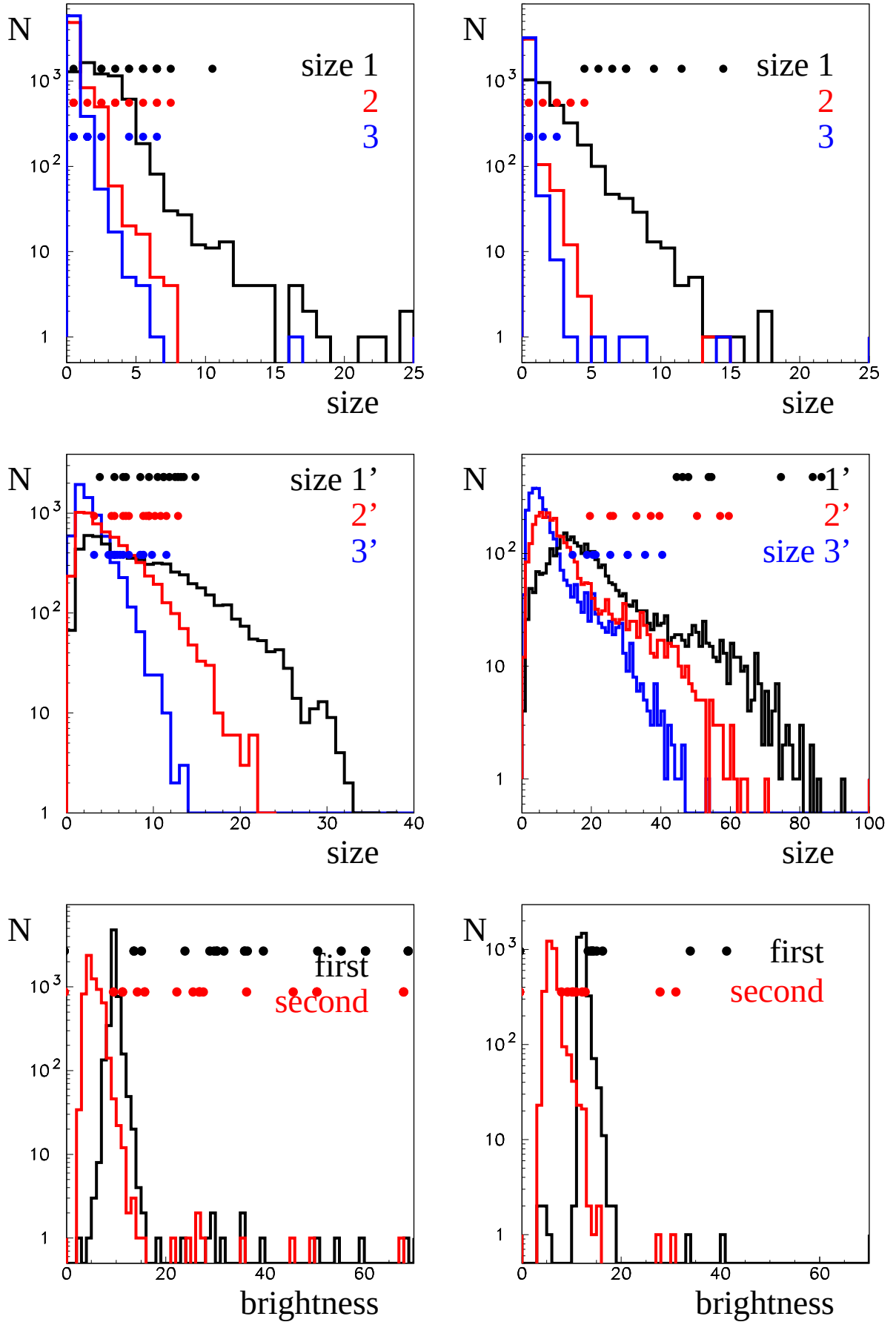


FIG. 3. Spectra of different size and brightness definition for 'normal' (left) and bright frame

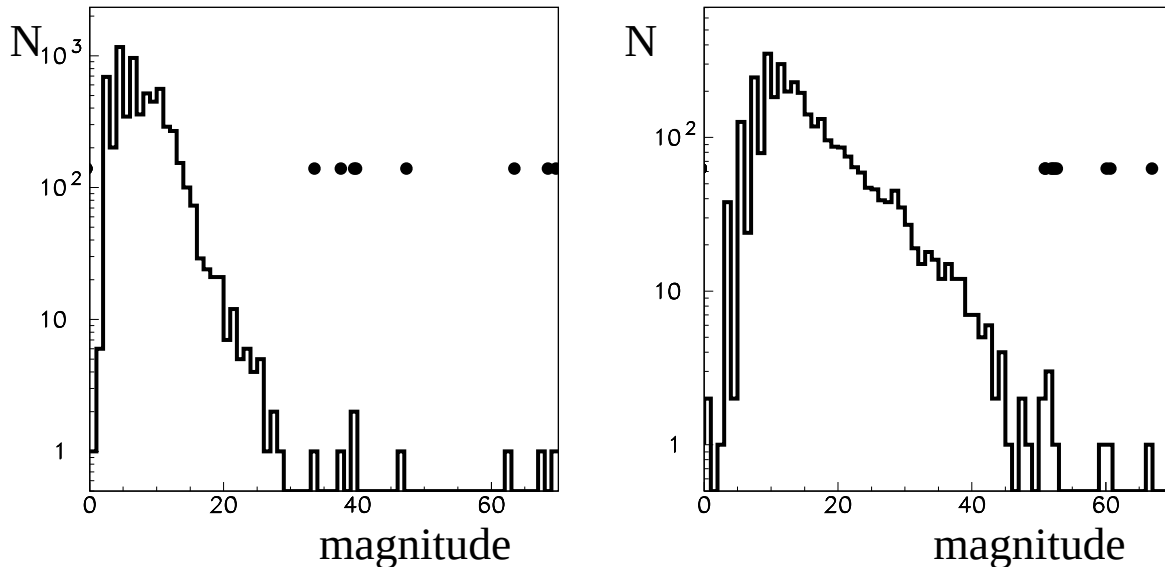


FIG. 4. Spectra of the magnitude measure for the same event sample as in Fig. 3

bright camera set (right plot) the tail is still seen.

We have a high level of confidence to assume that the event is this tails represents our sought cosmic ray particles. These events are marked by the solid circles in Fig. 4 and in all plots in Fig. 3.

We can look where the ‘muon events’ (dark circles) are distributed in all analyzed spectra. Important point is that in ‘brightness’ and ‘size’ measure spectra they are not separated as clear as they are in the ‘magnitude’ measure. The ‘brightness’ and all ‘size’ measures are much less effective than the ‘magnitude’,

IV. CONCLUSIONS

We proposed a cut shown in Fig. 4 and chose the tail events. All of them are shown in Figs. 5 and 6. The parameter for muon cut is probably taken too optimistic (too low). Some of events does not look very spectacular.

There is one more argument for their ‘cosmic origin’ - the rate. The first set of data was collected during almost 2 days giving the rate of about 1 event per 3 hours. The second, ‘brighter’ data set gives the rate almost exactly equal.

The last argument for proposed muon cut procedure, which is based, however, on small

statistics comes from the measurement when the camera which was positioned vertically. We observe there only two ‘suspected’ muon events during 16 hours.

But we have to say that we do not have a proof that the events selected by proposed procedure are real muon events. The further work in this direction is on the way.

V. FUTURE WORK

Our analysis was made with the old PC web camera. The resolution and quality of the iPhone cameras is much better and the similar analysis should be performed for true CREDO detectors. The results presented allows to create program which automatically sets the muon cut parameters and keep them tuned updating the camera performance matrices ‘on-fly’.

The further analysis and possible progress is possible when we can get the deeper access to the camera matrix and the raw signal data.

All this needs the modification of the general CREDO application which is in use for some time. The storage of the registration data in the iPhone memory would allow one to make the analysis of the muon cut in such case. There is no need (and no time, no space) for the transminnion of the registration to the main CREDO database.

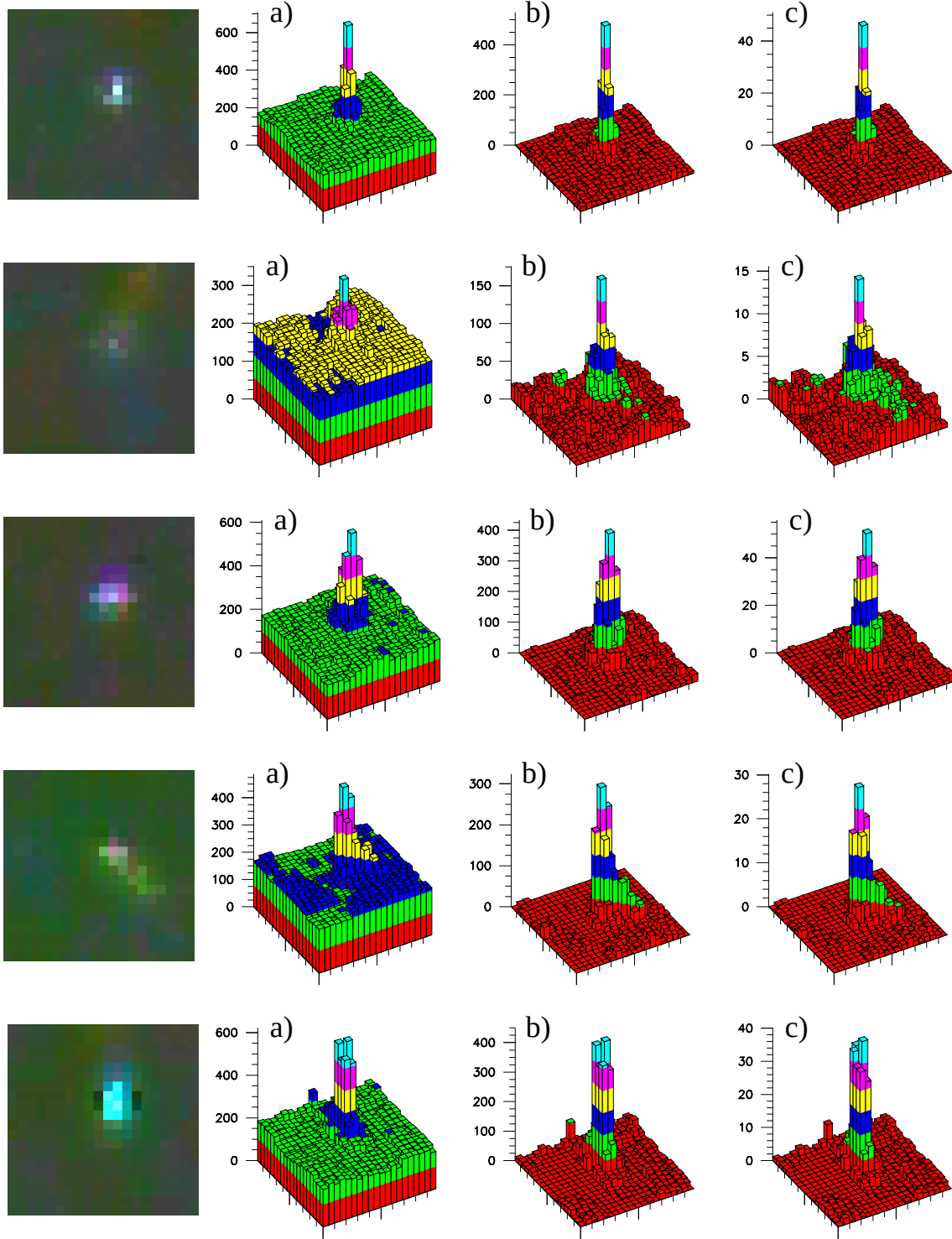


FIG. 5. ‘Bright big spots’ events - muon (probably) registered in a ‘normal’ bright camera conditions shown as in Fig. 2. Camera view and raw pixel contents a), difference $S_{i,j} - A_{i,j}$ b) and the difference scaled by the dispersion $(S_{i,j} - A_{i,j})/D_{i,j}$ c).

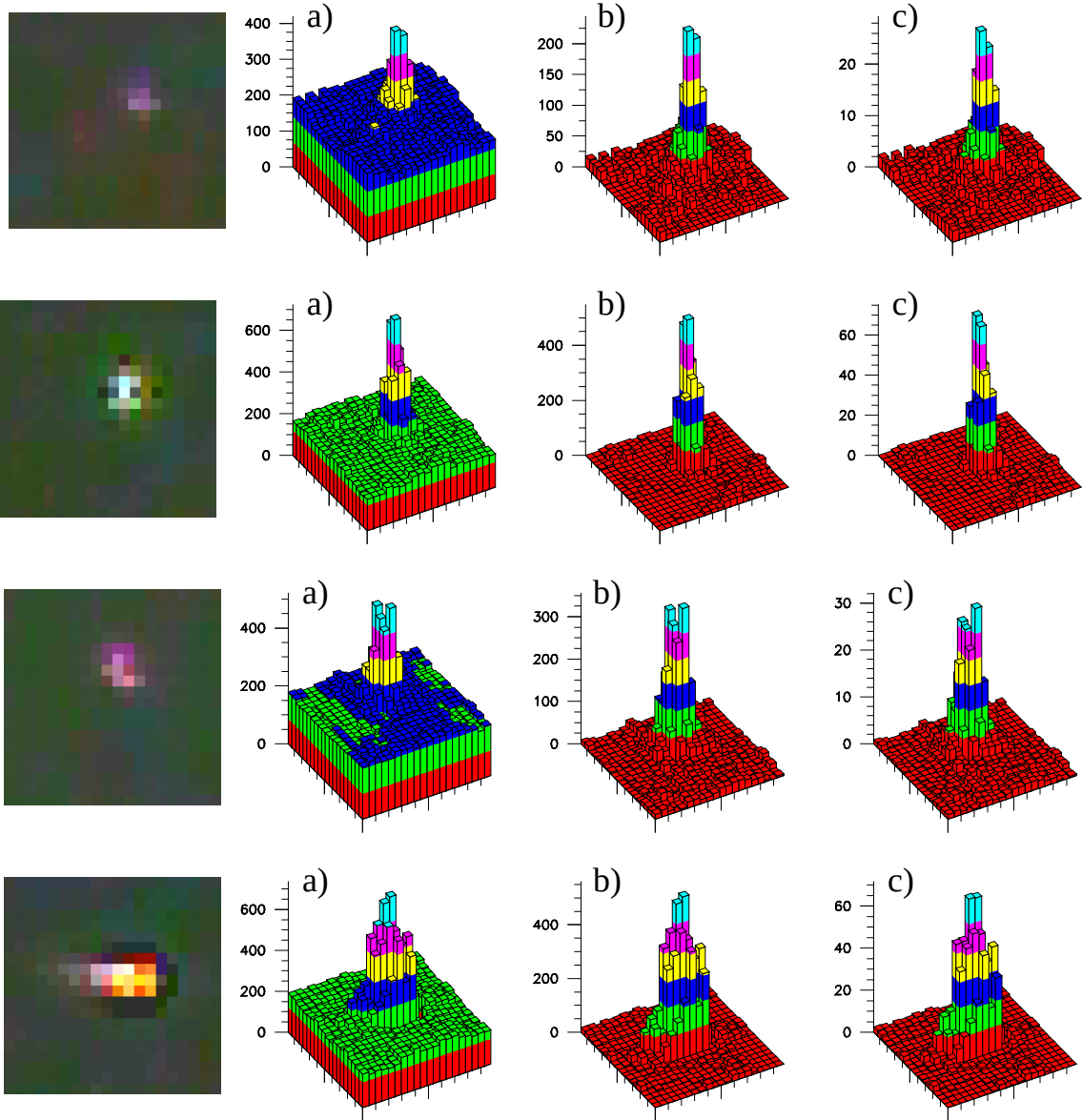


FIG. 5. (cont.)

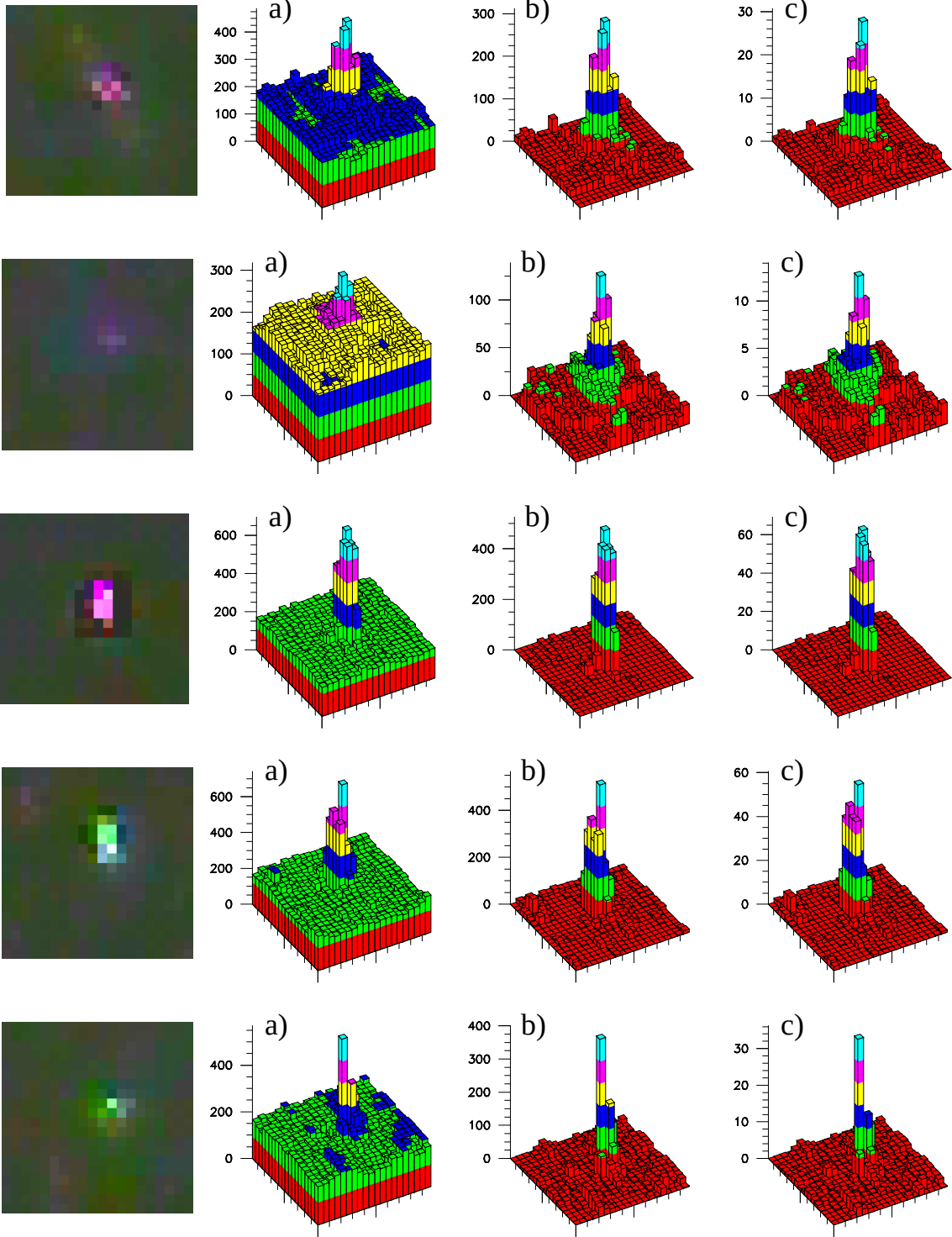


FIG. 5. (cont.)

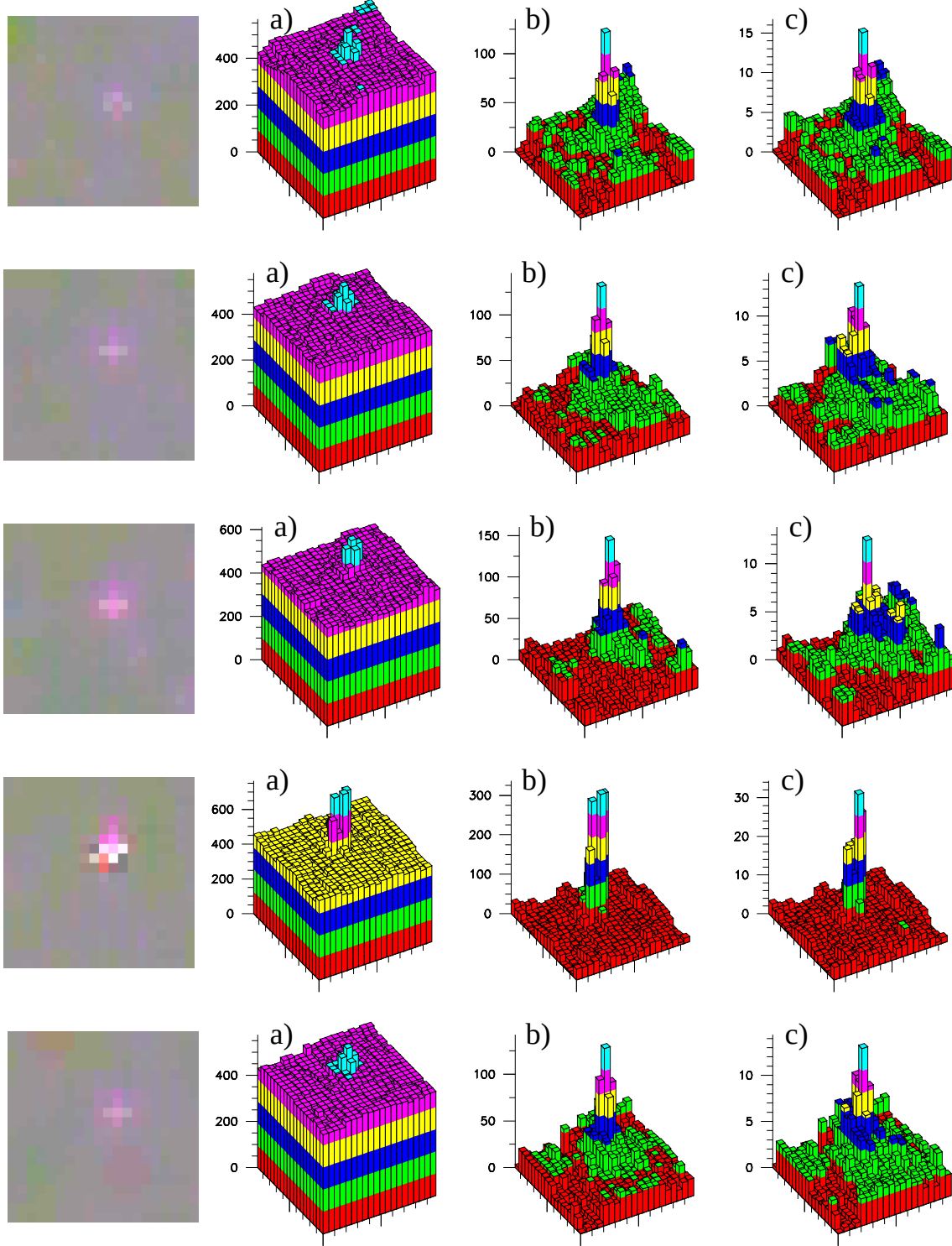


FIG. 6. ‘Bright big spots’ events - muon (probably) registered in a ‘very bright’ camera conditions shown as in Fig. 2. Camera view and raw pixel contents a), difference $S_{i,j} - A_{i,j}$ b) and the difference scaled by the dispersion $(S_{i,j} - A_{i,j}) / D_{i,j}$ c).

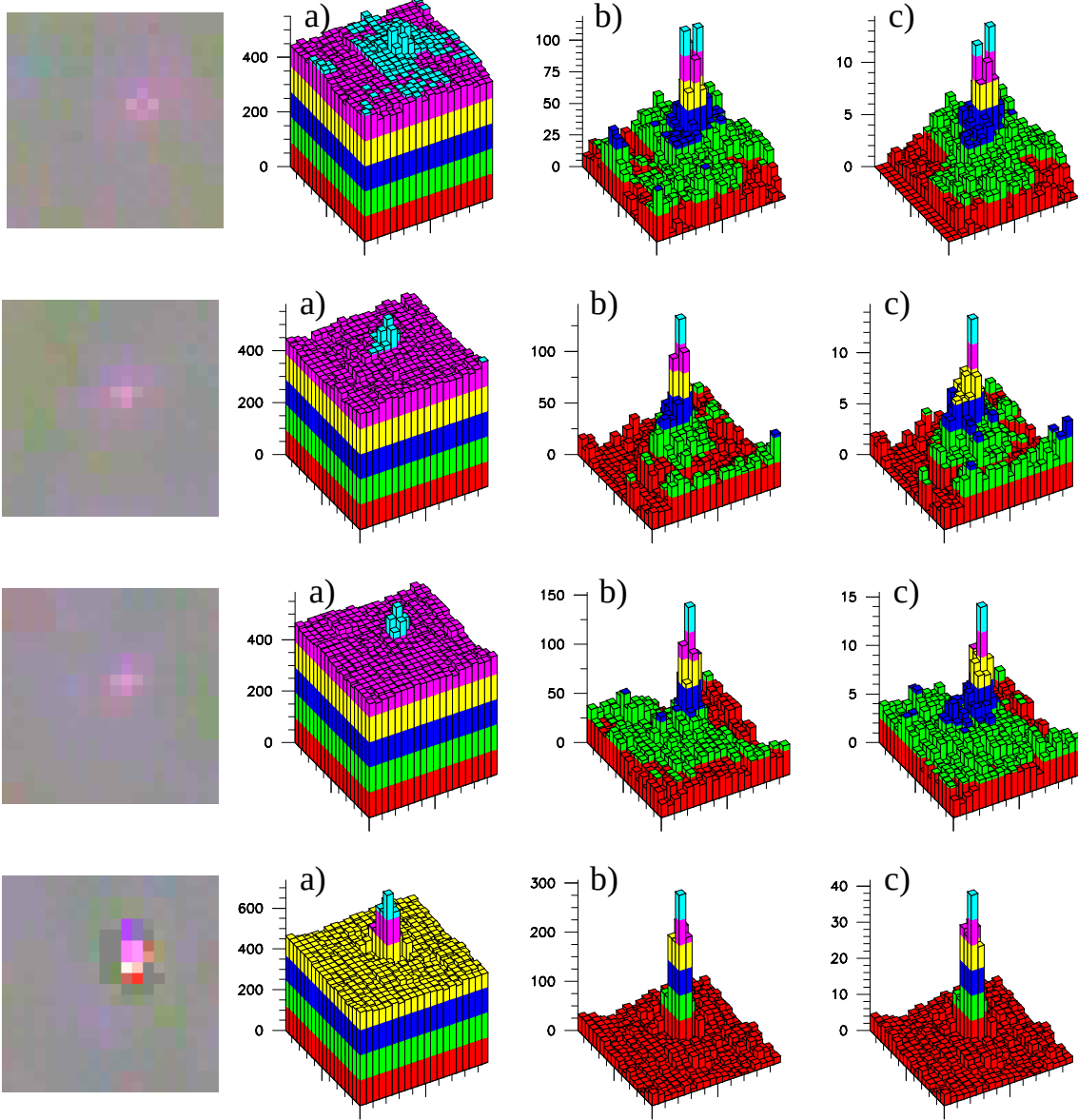


FIG. 6. (cont.)