MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescope

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Report on Progress of Night Sky Background Reduction

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Abstract

We would like to present some results concerning the so-called Standard Night Sky Background Subtraction and our investigations to improve the MAGIC image cleaning procedure and to find some other (better) non-χ^2 method of finding the image parameters. Concluding these searches we have to say that no significantly better methods were found. We have checked, if one, promising at first sight, way of analyzing noisy images known as Hough transform method, can be applied to MAGIC Cerenkov images. Further, the more conventional band filter method of picture cleaning based on wavelet analysis has been tested.

We concentrate our efforts on low energy shower images, where the simulated data are very noisy and thus hard to analyze. Some advantages of our, bit more sophisticated, treatments can be seen, but mainly due to the much higher computer time consumption they do not look very useful as the "standard" MAGIC data analysis tools. Thus this reports could be interested mainly to those who want to continue such searches and, may be, it can save their time.

1 Standard Night Sky Background Substraction

The Standard Night Sky Background Substraction (SNSBS) is the procedure using the camera output matrix as input data and the array of average pedestal signals and its standard deviations for each camera pixel to decide which pixels should be further used for image parameter determination.

Each pixel the 16 FADC chanel contents are sampled using a time window. For the present analysis its width waschoosen to be of 5 FADC channels (from third to seventh) wereused. This is of about 15 ns from the shower front, so most of the showerCerenkov photons is counted. Sum of them forms "signal" for each pixel. Then the signal was reduced by the average pedestal for the pixel obtained from the same showers summing channels from 10 to 14 and compared with such obtained pedestal signal widths.

The cleanning parameters are the factors by which the width of the pedestal distribution is multiplied before comparison with the actual pixel signal to count the pixel as "used" ("core") ones.

We have examined if the values based on the experience of HEGRA CT experiments (3 and 2.5) are the best or something better can be found. We would like also to examine applicability of the SNSBS method at very low energies.

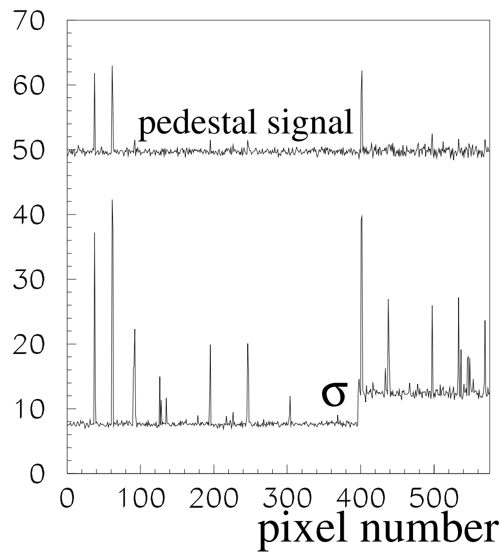


Fig.1 Average signal and its SD for each camera pixel.

The average pedestal signals found for sum of 5 FADC channels as well as their standard deviations are given in Fig.1. The excess seen in some pixels is due to some stars in the field of view (we used here the "CrabNebula region" of the sky).

We simulated of about 1000 γ-EAS for 6 different energies from 20 GeV to 1 TeV producing two sets of camera output samples: one without NSB introduced to the program and the second with simulated NSB.

For the first set we calculated shower image parameters using all pixels hit by shower photons without any cleanning procedure. These parameters were further used as "true" (reference) image parameters for a comparisons of different SNSBS methods and parameters.

The second simulated shower sample was then treated with SNSBS with different values of cleanning parameters and then image parameters were determined and compared with the reference sample values.

The first and important parameter is the "efficiency" of the SNSBS method. If the cleanning parameters are higher then less images (for low energy events) survives the cut. This is seen in Fig.2 where the fraction of the shovers for which the Hillas parameters can be found is shown as a function of paricle energy for different sets of cleanning parameters. As it can be seen is is quite sensitive in the small energy region.

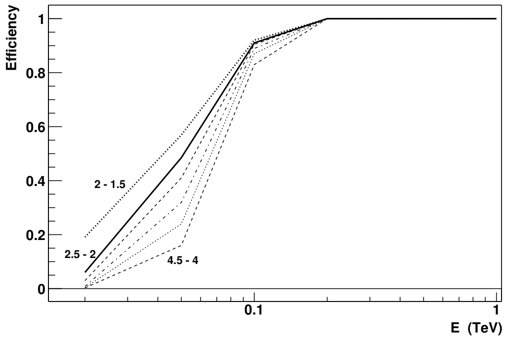


Fig.2 The "efficiency" of the image parameter reconstruction.

Then the comparison was made but only for the showers which are big enough (survives the cleanning) and also good enough to be used for gamma/hadron separation. The second is defined as the requirement of the parameter DIST calculated for their reference images is greater than 80 mm and their ALPHA parameter (also from reference - without NSB - sample) is less than 30°.

We compared the values for reference sample and cleaned showers using three characteristics. The first is the correlation coefficient. The second – mean bias introduced by NSB and the SNSBS method which is seen in the average difference between the reference and cleaned values. The third is the additional uncertainty introduced by NSB and the SNSBS method shown as the difference between widths of respective perameter distribution for reference and cleande shower samples.

The most important parameter is the ALPHA, and results concerning its values are given in Fig.3. Next two figures (Figs.4 and 5) present the dependencies found for LENGTH and WIDTH parameters.

As it can be seen from the figures below the SNSBS method for HEGRA values of the cleanning paramters works well, but it is slightly better to choose the smaller values 2.5 and 2 (thick solid lines in the graphs) which improves the efficiency as well as the bias for all parameters under investigation. However the difference is not very big, and it will not improve the analysis results subtantially.

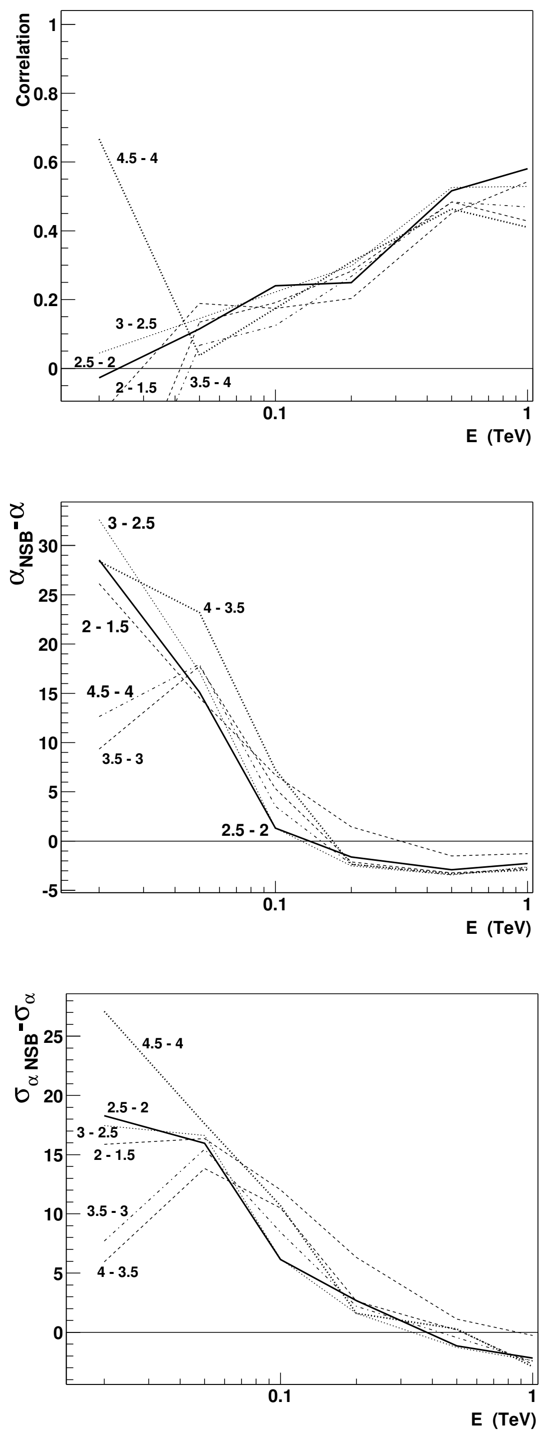


Fig.3. The correlation coefficient (top), mean bias (middle) and widths difference (bottom) for the ALPHA parameter for different cleanning parameters as a function of shower γ energy.

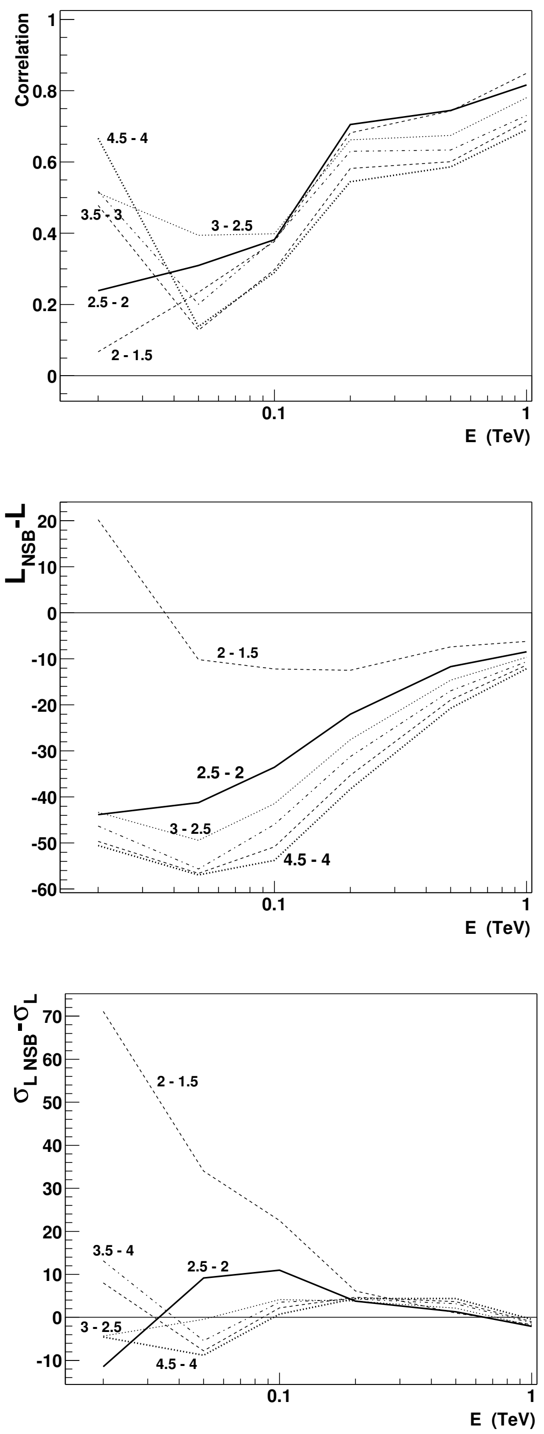
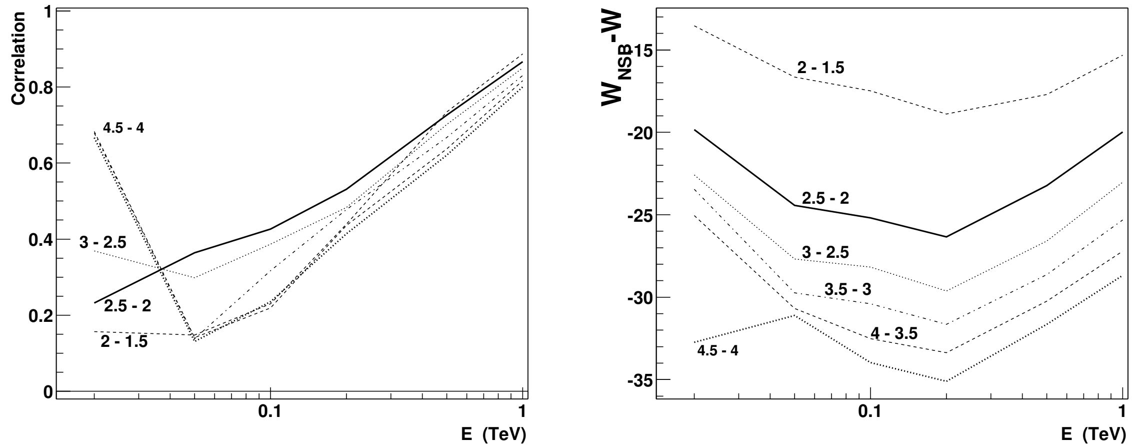


Fig.4. The correlation coefficient (top), mean bias (middle) and widths difference (bottom) for the LENGTH parameter shown as in Fig.3.



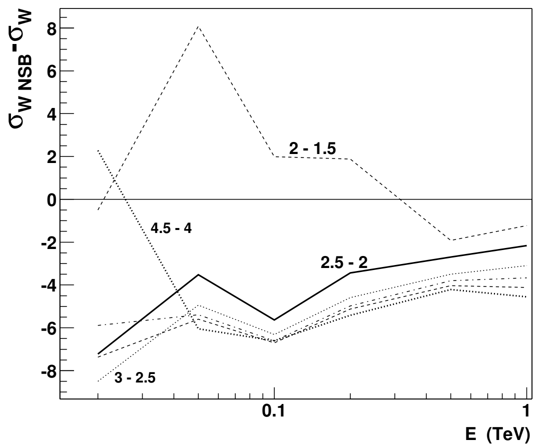


Fig.5. The correlation coefficient, mean bias, and widths difference for the WIDTH parameter shown as in Fig.3.

2 Hough transform

The Hough transform works in $(x \times y)$ plane. Each point is transformed to the line in $(r \times \Phi)$. Each point in Hough plane $(r \times \Phi)$ represent straight line in $(x \times y)$ as it is shown in Fig.1. The respective formula is:

$$r = x \cos(\Phi) - y \sin(\Phi) \quad .$$

If there are some points on one straight line in $(x \times y)$ their Hough images will cross at one point in $(r \times \Phi)$. This is the general idea of the Hough method. In the case of the MAGIC like data for each camera pixel we build its Hough image and make the loop over all pixels weighting lines by the amplitude of the signal in each pixel. Then we look for the point in $(r \times \Phi)$ with the highest value in its neighborhood.

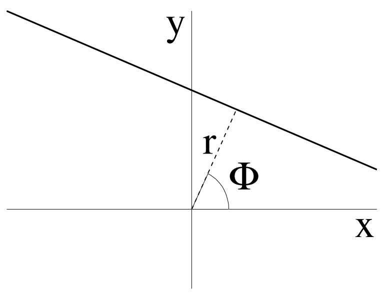


Fig.1. The relation between $(x \times y)$ plane and the Hough r and Φ coordinates.

The main advantage of this method is its robustness. We do not have to exclude the random background in the $(x \times y)$ plane (the night sky background (NSB) in the MAGIC case). An example of this is shown in Fig.2. The "true" image is build of some pixels along the line (dashed boxes) and some background is then introduced (open squares). As it is seen the Hough reconstruction of the line (its position and direction defined by r and Φ) works quite well.

To apply the Hough transform method for finding directions of the Cherenkov shower images in MAGIC some "smoothing" in the Hough plane was applied due to the fact that the showers are not exactly straight lines, but this was found to be not very critical.

Using this method only two parameters of the shower image can be found. The generalization to higher dimensions is in principle possible, but first, the information contained in the digitalized camera output is too poor in most of interesting cases of low energy showers, and the time of calculations increases making the method for more than two dimensions practically useless.

One of the Hough parameters r is exactly the Hillas MISS parameter. The second is the direction of the image longer axis which can be related to the ALPHA parameters when the position of the image center is known. To be consistent we define it as the point on the Hough "best" line closest to the pixel on the line with the highest amplitude.

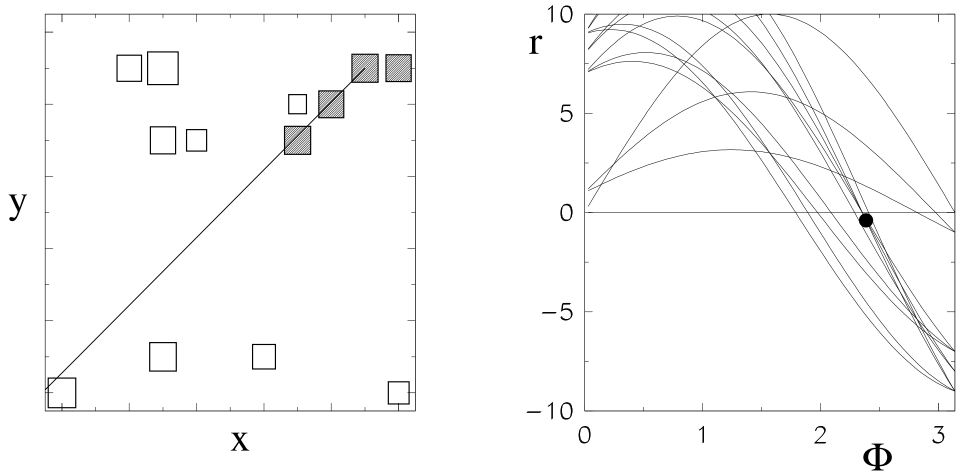


Fig.2. The “image” in $(x \times y)$ (left) and its representation in $(r \times \Phi)$ plane (right). The black dot (in right plot) shows “the best” line parameters. This “best line” is shown in the left figure.

It is clear that the Hough transform method is more “efficient” than the standard image cleaning and using well known Hillas formulas. For every “noised” shower the best line can be found. As a reference we took the sample of the same showers simulated without NSB with all the Hillas parameters obtained without any cleaning procedure. They represent “true” values. We define here the efficiency of the method as the fraction of showers for which parameters can be estimated. The energy dependence of the efficiency is given in Fig.3.
Introducing the NSB to compare the Hough method with “standard cleaning procedure” (SNSBS) with parameters 2.5 and 2.Results of the comparison are shown in Figs.4 and 5.
In Fig.6 the correlation coefficient between Hough found ALPHA and MISS and reference sample (“not-so-bad” showers defined as these for which in the reference shower sample simulated without NSB the DIST parameter is greater than 80 mm and ALPHA was found to be less than 30°) parameters are given and compared with the correlation found for SNSBS. For the same showers the difference between parameters estimated with a help both methods and the reference values and the difference between widths of respective distributions is also shown in Fig.6.

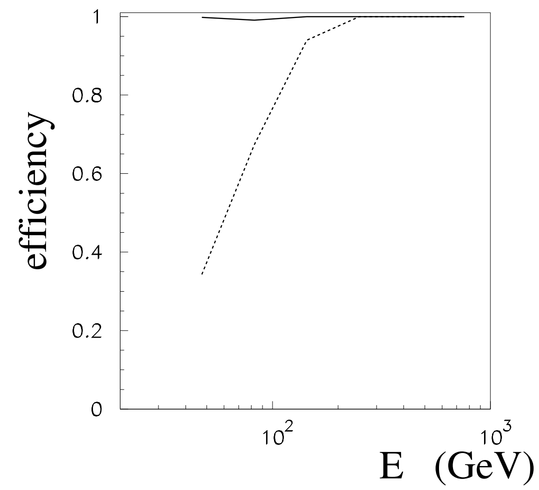


Fig.3 Efficiency for Hough method (solid line) compared with SNSBS (dashed).

The general conclusion which can be drown is that even if some improvement can be found it is not very significant – not so significant that the method can be used instead of standard χ^2 Hillas parameter fitting. However due to its robustness it can be used as some cross-check method when the real data will be available.

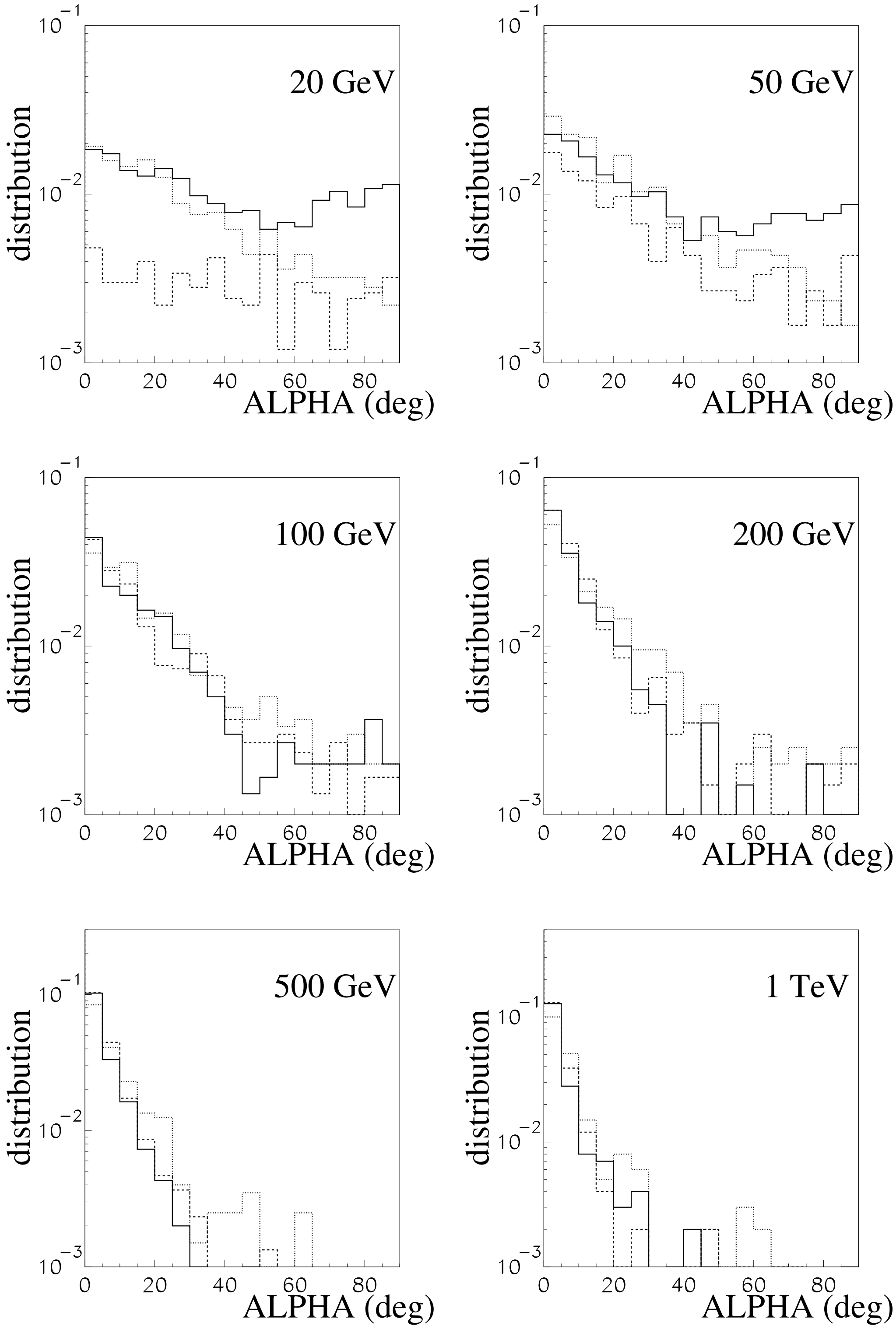


Fig.4 ALPHA parameter distributions for different shower energies. Solid histogram represents result of the Hough transform method, dashed the standard cleaning (with parameters equal to 2.5 and 2.0 respectively) and dotted – reference images without NSB and cleaning.

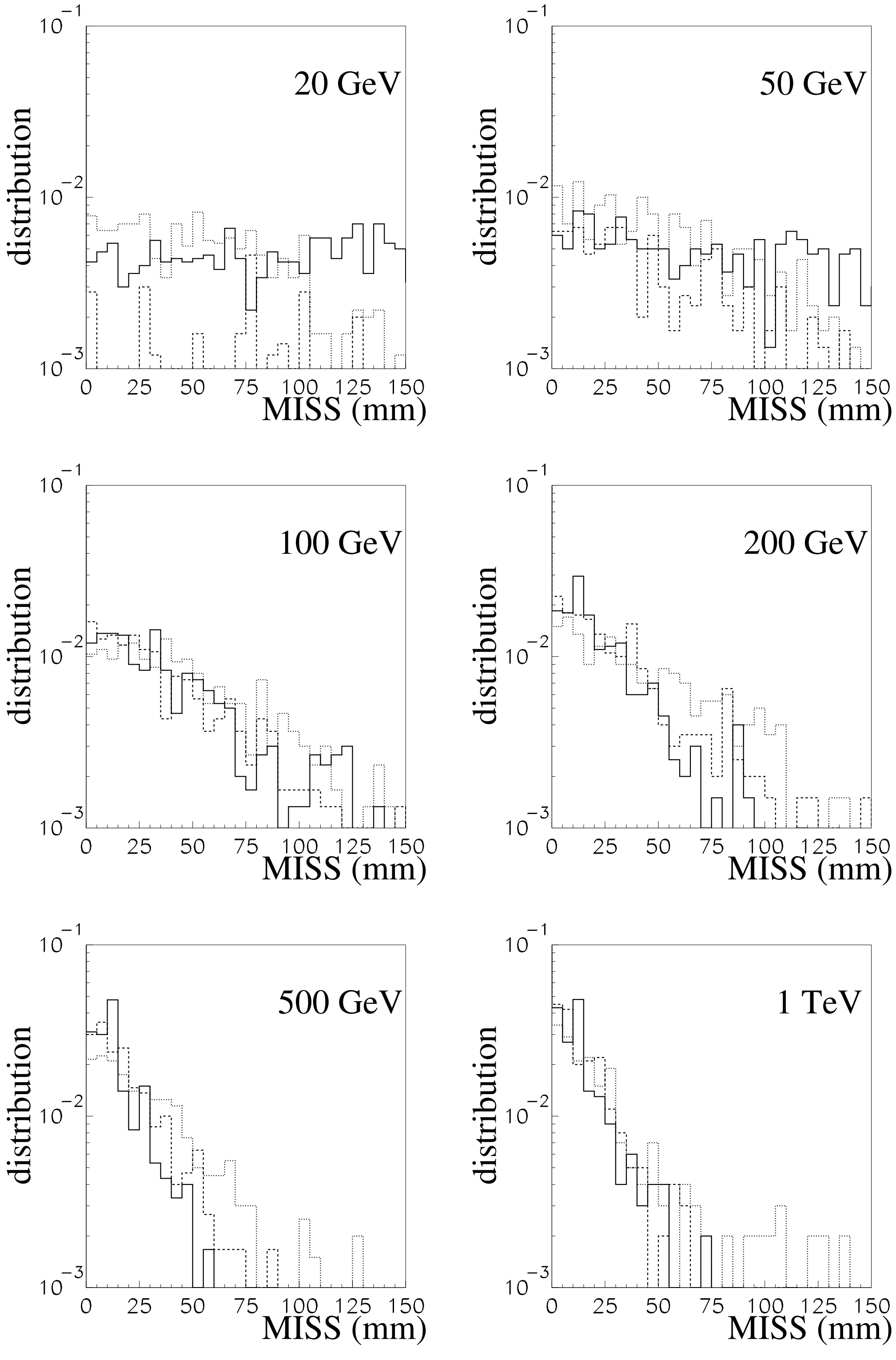


Fig.5 MISS parameter distributions for different energies. Lines description as in Fig.4.

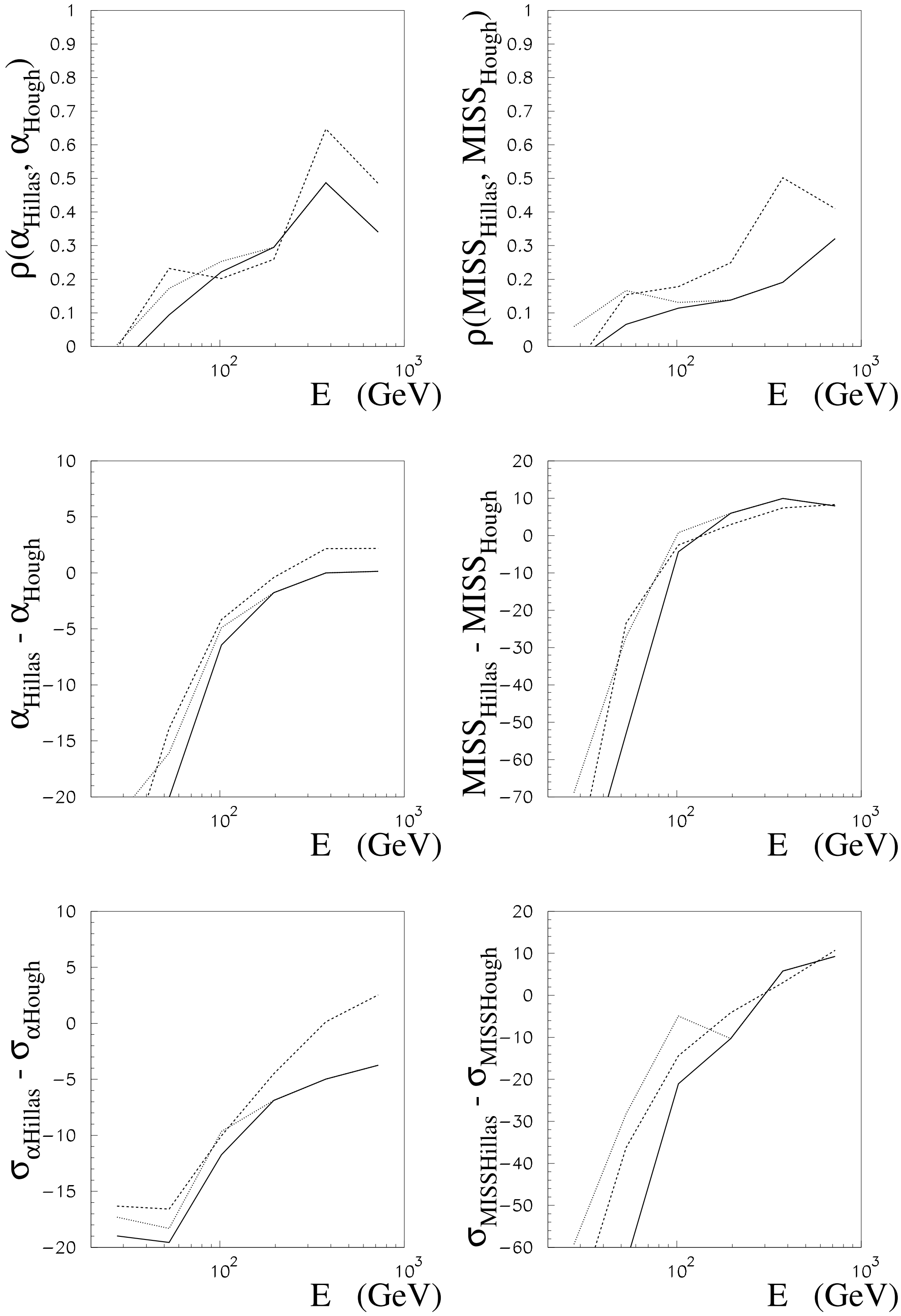


Fig.6 Correlation (top), difference of average values (middle) and distribution widths (bottom) for ALPHA and MISS parameters calculated with Hough transform method (solid lines), SNSBS (dashed) and Hough applied only for these showers for which SNSBS parameters can be determined (dotted). As a reference the events without NSB were used.

3 Wavelet denoising

Wavelet analysis is becoming a common tool for analyzing variations within space and time of clustering phenomena. It is also essentially a bandpass filter which can be used for denoising data. We used this method for MAGIC images of Cerenkov photon showers.

The hexagonal structure of the MAGIC camera makes the conventional 2-dim wavelet analysis rather complicated, therefor we map real two-dimensional image to one dimensional data structure simply by using the pixel numbering scheme. Each shower is then a sequence of 577 amplitudes (sum over 5 channels in FADC). In real shower case the data set is expected to have a "short" range correlation between channel contents (with scales of order of width of the shower image) as well as long range ones related to the periodic structure of the camera from one ring of pixels to the next one.

Using the particular mother wavelet function the power of correlation for each scale can be determined. It should be mentioned here that there are significant differences between the wavelet and well known Fourier analysis. The most important one is that the wavelet transform map the 1-dim, linear, input series (say, in position space) to 2-dim plane (position $\times$ frequency) structures. There are obvious advantages of the wavelet method comparing to the Fourier making it much more useful for denoising procedures. Thus it is interesting how it work for MAGIC telescope data.

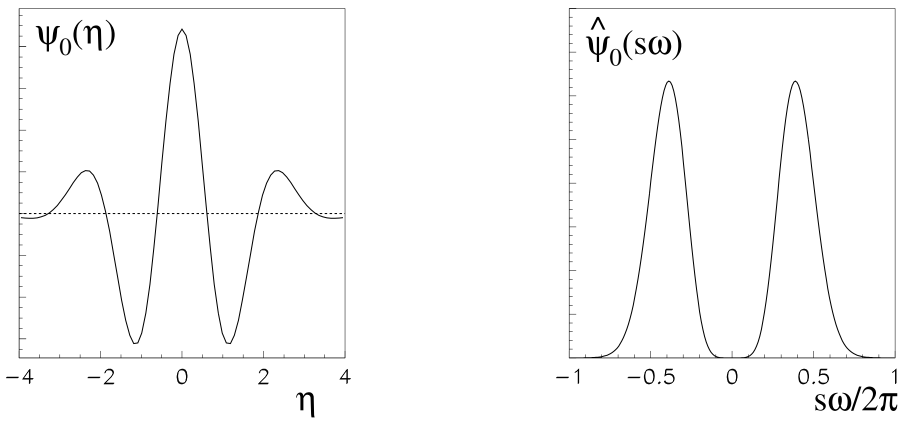


Fig.1. The mother DOG wavelet (left) and its Fourier transform (right).

For the present analysis due to the limits of the input data (577 values) we have chosen the non-orthogonal wavelet "basis" and the continuous wavelet transform. We have tested few of mother wavelet functions and did not found any significant differences between them. The results which will be given are for so-called DOG (derivatives of a Gaussian) of order of 6 wavelet. It is shown in Fig.1. The construction of wavelet spectrum can be speed up significantly using Fourier transforms both for wavelet function and input data (and FFT routines for the numerical code). In such case the wavelet spectrum coefficient are given as:

$$W_n(s) \;=\; \sum_{k=0}^{N-1} \hat{x}\,\hat{\Psi}^*(s\,\omega_k)\exp(i\omega_k\,n\,\delta t) \quad ,$$

where $\hat{\Psi}$ is shown in Fig.1. s is the wavelet scale factor (related to the frequency in the Fourier analysis).

The wavelet power spectrum is $\mid W_n(s)\mid^2$ for each pixel n. If summed over all pixels it gives the global power spectrum. With the proper normalization for the white noise only $\mid W_n(s)\mid^2 = \sigma_n^2$. In the MAGIC case, as could be expected the global power spectra have (in most cases) two clear peaks. One for mentioned short range, and the second for long range correlations.

In Fig.3 some examples of the global power spectra for simulated MAGIC events are given.

The reconstruction using the limited band of wavelet scales (frequencies) can be done easily

$$x_n \;=\; \frac{\delta j}{C\Psi_0(0)} \sum_{j=j_l}^{j_u} \frac{\Re\left(W_n(s_j)\right)}{s_j^{1/2}} \quad ,$$

where $\Re(W)$ is the real part of respective wavelet coefficient and j_l and j_u are limits chosen to get the best results (depending of particular purposes). Resulting denoised data are presented in Fig.3 for some simulated showers. As it is expected the random noise is suppressed.

Then for each cleaned event the standard cleaning procedure is applied and Hillas parameters of the image are calculated. The fraction of events for which Hillas parameters can be calculated is given in Fig.2. The wavelet denoising does not change it significantly.

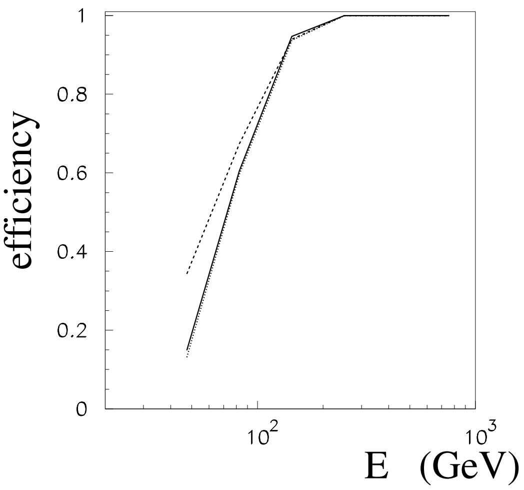


Fig.2. Efficiency of calculating image parameters for wavelet filter (solid line), and standard cleaning method without denoising (dashed).

We have applied the wavelet denoising procedure to 6 data sets of energies 20, 50, 100, 200, 500, and 1000 GeV. In Figs.4 and 5 we present the distributions of Hillas parameters ALPHA and MISS for these showers. There are histograms for our reference sample containing the same simulated showers but without NSB (dotted lines). The wavelet denoising method resulting histograms are given by the solid lines and they are compared with SNSBS procedure (with parameters 2.5 and 2.0).

Then we calculated the correlation coefficient between reference sample (without NSB and cleaning containning only “not-so-bad” showers) and images denoised and the same showers cleaned in the standard way for ALPHA, MISS, DIST, LENGTH, WIDTH, and SIZE parameters. Results are presented in Fig.6 as a function of shower energy.

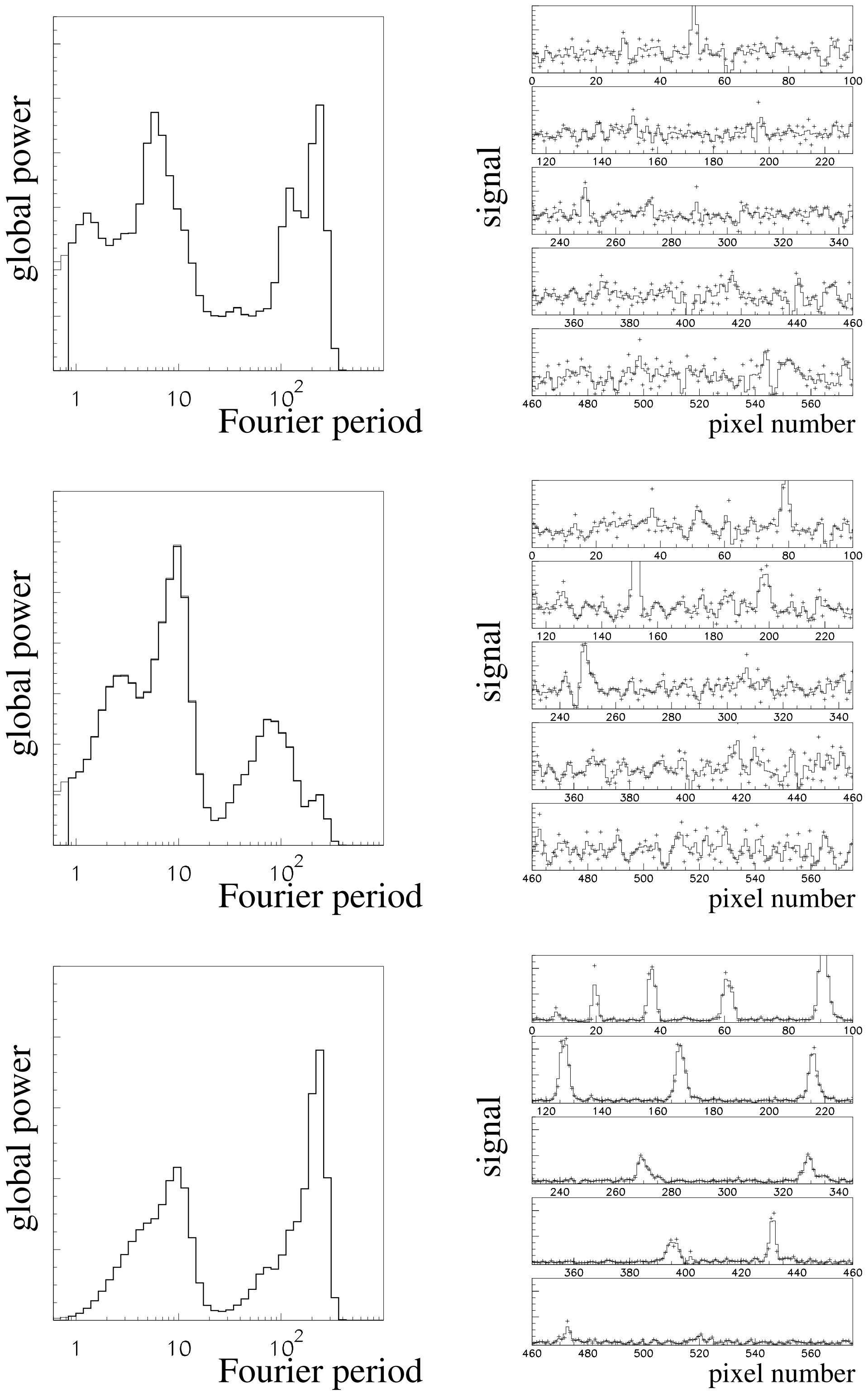


Fig.3. Examples of an event global wavelet power spectrum (left) and result of wavelet denoising procedure (right) for energies of 20 (top), 100 (middle) and 1000 (bottom) GeV. Crosses are input values and lines show outputs.

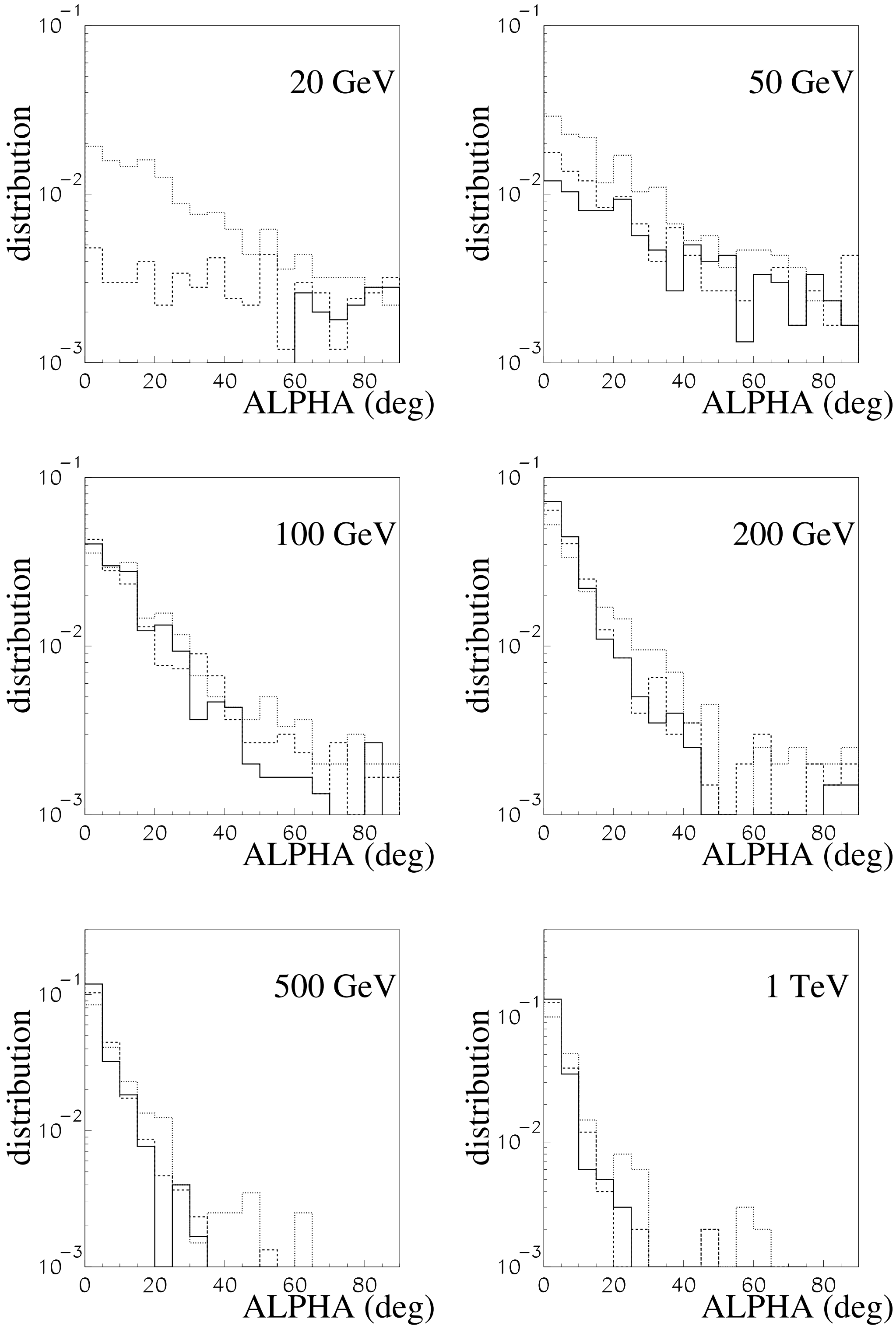


Fig.4 ALPHA parameter distributions for different shower energies. Solid histogram represents result of the wavelet filtering, dashed the standard noise reduction (with parameters 2.5 and 2), and dotted – for images without NSB background.

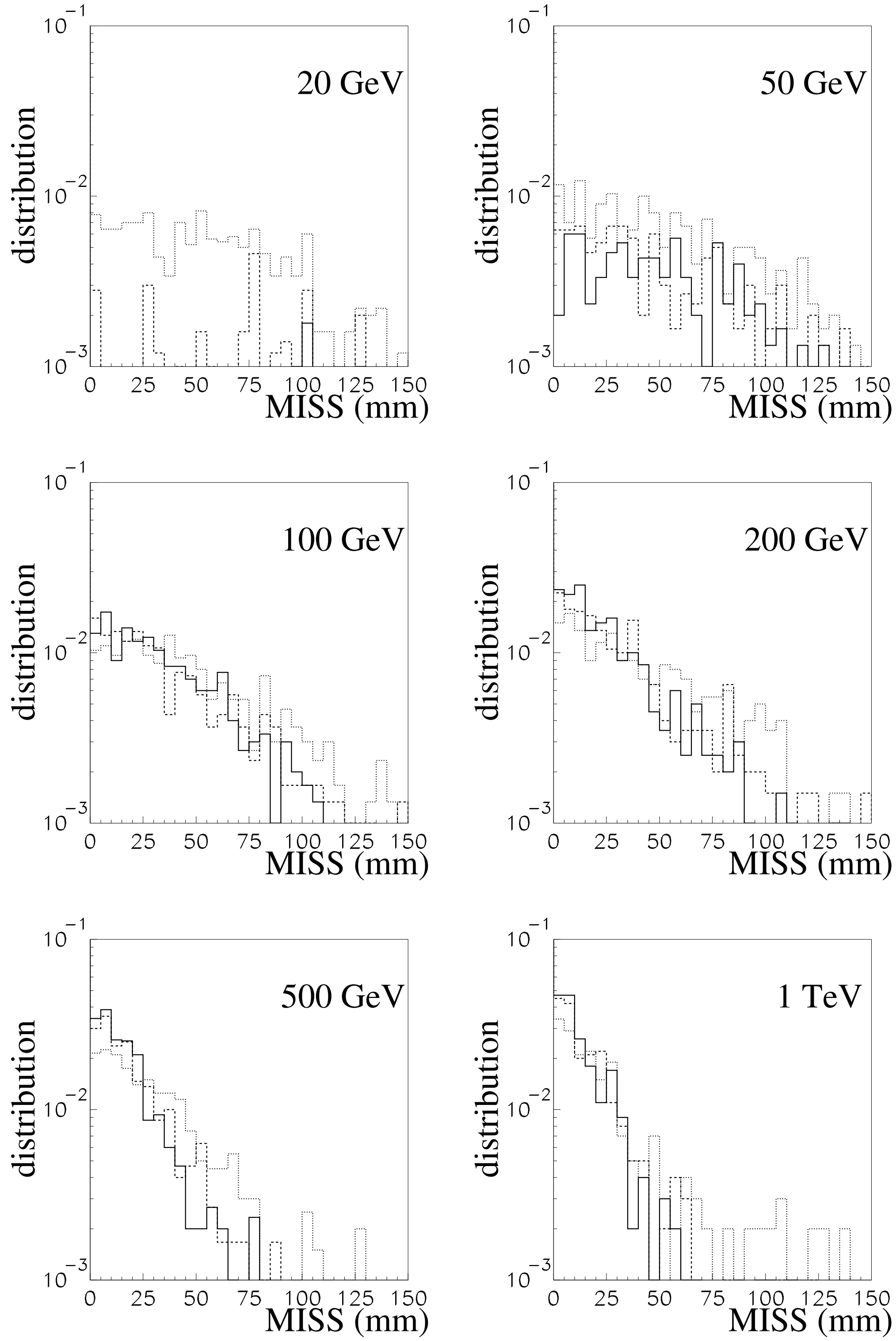


Fig.5 MISS parameter distributions for different energies. Description as in Fig.4.

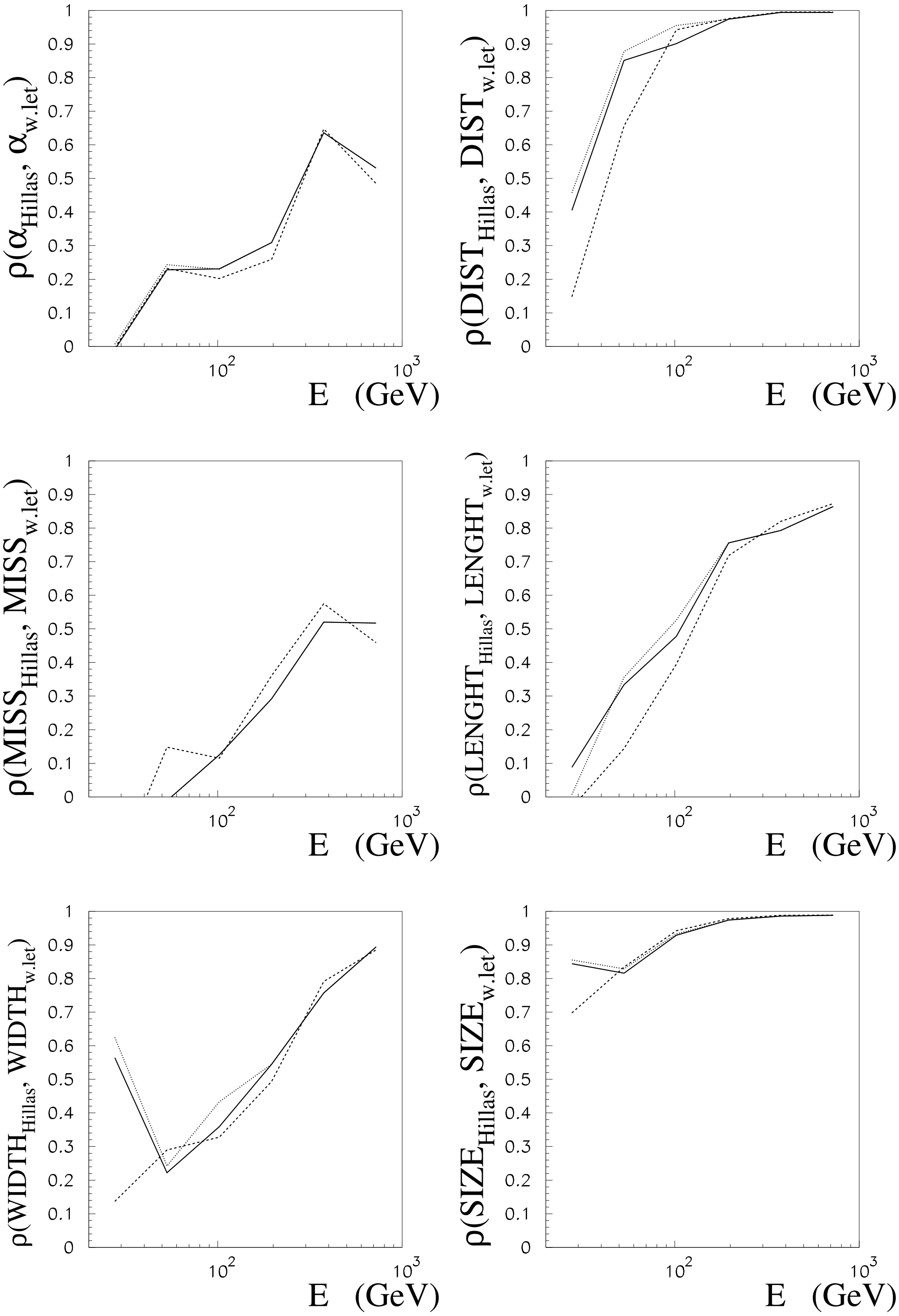


Fig.6 Correlation coefficient for ALPHA, DIST, MISS, LENGTH, WIDTH and SIZE image parameters. Reference values are for images without NSB. Solid lines are for wavelet filtered images, dashed – for SNSBS procedure (2.5, 2.0). Dotted lines are for wavelet filter but only for these images for which the SNSBS could be applied successfully.

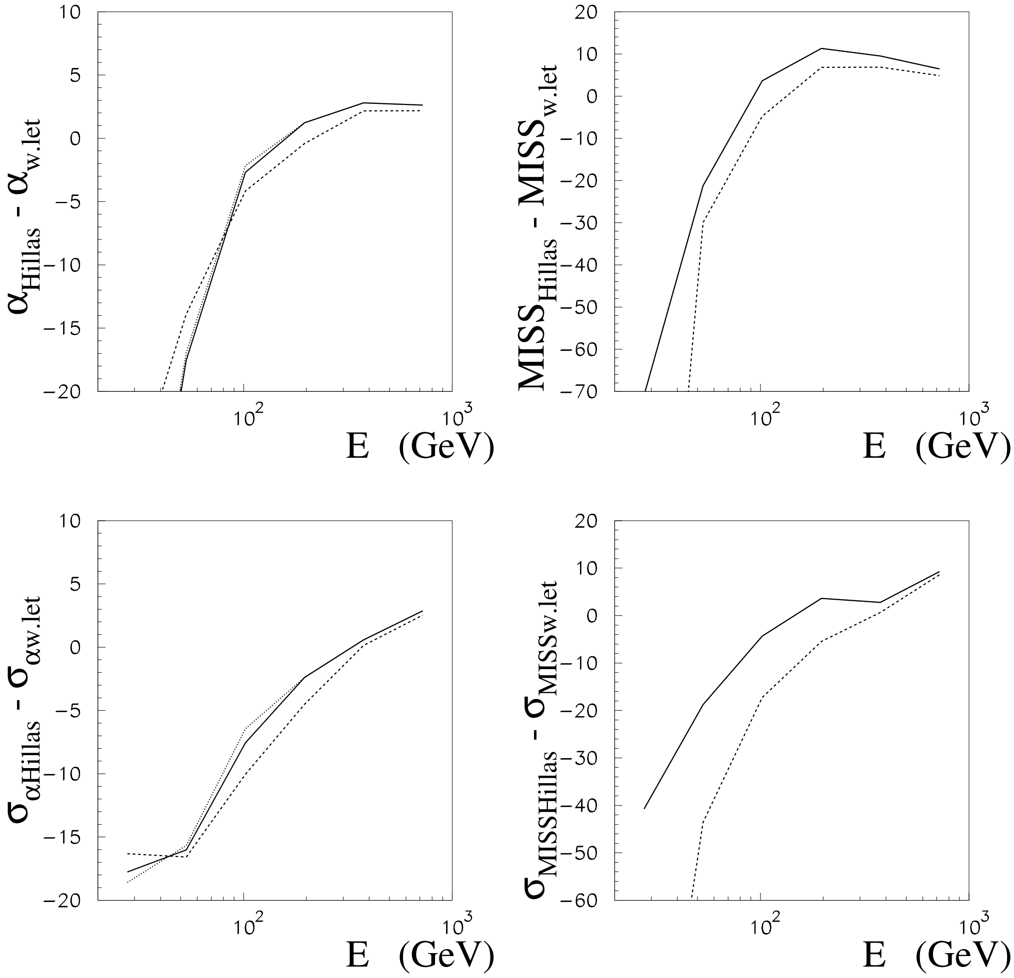


Fig.7 Difference between average values of ALPHA and MISS parameters (top) and between widths of respective distributions. Lines description as in Fig.6.

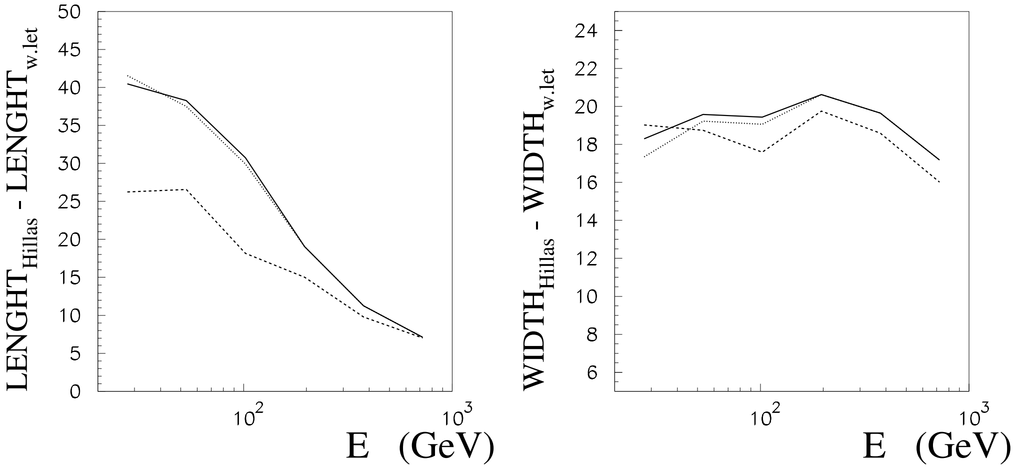


Fig.8 Difference between average values of LENGTH and WIDTH image parameters in reference sample and these obtained as described in Fig.6.

4 Conclusions

There is a general remark concerning the eventual conclusions. Any of them ought to be made with care. The first reason is that the main source of the noise in the MAGIC camera images analyzed here is the electronic noise, not the real night sky photons. It is simulated using simplified formulas which have to be tested with the real apparatus as soon as it is possible. So, the analysis presented is valid only to the extend given by the accuracy of the electronic noise simulations. The second reason is that the denoised images have been compared with the camera images simulated with no nigh sky photon background, but with the electronic noise included, so that all the reference showers were in fact noisy somehow. The physics of the γ showers coming from the direction of the telescope axis tells us that the "true" ALPHA (and MISS) parameters of these showers should be exactly 0. Thus the question arises: if it is better to look for the deviation from the value of 0 (for, e.g., ALPHA) looking just at the width of the ALPHA distribution, or to the correlation coefficient between showers with and without NSB, and which procedure will give more trustfully results.

It is (may be) slightly surprising that the difference between the same shower parameters obtained with and without NSB photons is so big (as can be seen in the Figures). It is represented by small values of respective correlation coefficients. This makes the searching for γ/hadron separation methods for simulations without NSB (and its subtraction procedure) and without carefully adjusted electronic noise rather questionable at low energies (say below 100–200 GeV) where the showers are relatively small.

The problem of very low energy events is not only in the fact that one would like to measure fluxes (of γs) at energies as low as possible, but also in that, that they can contribute substantially to the measurements at higher energies just mimic bigger showers, especially, if we do not reconstruct them correctly.

We think that this needs some additional studies. However, their will be of some value only when the electronic noise is measured and simulated according to this measurements.