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A data analysis preprocesing; the effect of the Earth magnetic field on the MAGIC shower images.

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Abstract

Distributions of the γ cascades image parameters are different for the fixed zenith angle but different azimuth angles due to the influence of the Earth magnetic field on the shower development in the atmosphere. In this note we present the procedure developed to take this into account when analysing MAGIC data. We have used simulated gamma showers with zenith angles (mark as **Z**): 10°, 20°, 30°, 40° and azimuth angles (mark as **A**): 0°, 30°, 60°, 90°, 180° (for Z=10° only A=0°, 90° and 180°). In each case 100 000 events were simulated. Proposed method found very simple. Parameters obtained for simulated showers nicely fit a smooth dependence on the angle between shower axis and Earth magnetic field. Thus we believe it can be used to compare results of observations of low energy events for different MAGIC telescope orientation.

Contents

1 The dependence of the Cherenkov simulated images on azimuth angle (A).

In Figure 1 we have compared the image parameters distributions of the shower (which fulfil conditions needed for the Hillas parameters calculation) at Z=40° and A=0°, 90°, 180°.

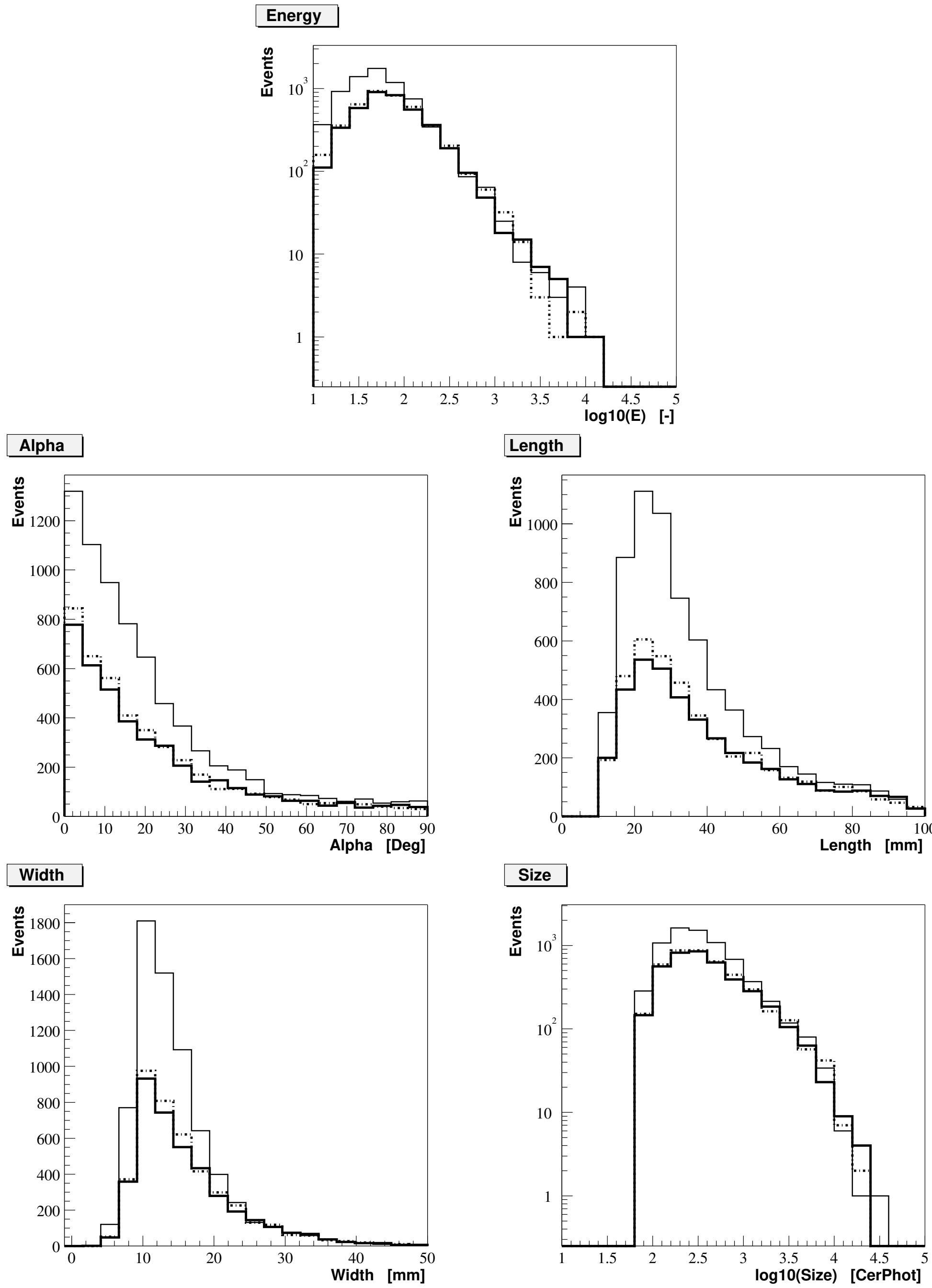


Figure 1: Energy spectra and selected Hillas parameters of γ's which fulfil "Hillas parameters calculation conditions" for zenith angle Z=40°. Thin solid line is for A=0°, dot-dashed line is for A=90° and thick solid line is for A=180°.

It is clearly seen that (specially for low energy events) the fixed MAGIC telescope trigger leads to significant differences in the registration efficiency. This makes difficult to compare fluxes measured at different telescope orientations. To avoid this the special procedure was developed and will be described below.
The main reason of differences of Cherenkov's images is the Earth magnetic field. Let us denote the angle between the axis of the shower and the magnetic field direction as **K**. Figure 1 shows, that the largest effect is seen for histograms for A=0° and A=90°.

In the Table 1 the list of used simulated shower samples is given with the corresponding value of the angle K. In the last column we put the number of events for which the calculation of Hillas parameters was possible (after image cleaning on the level 2.5 and 3 sigma). It is proportional to the reconstructed event rate. From the Table 1 one can see that even for fixed Z the rate is different for different azimuths. We have first analysed ratio of number of events for A=0°, 30°, 60° which pass "Hillas parameters calculation trigger" to number of events with A=90° which fulfil the same conditions (denoted hereafter as: A=0°/A=90°, A=30°/A=90°, A=60°/A=90° (see Figure 2)). [For Z=10° we have compared only one pair: A=0° and A=90°, because the corresponding angles K were very similar. Above the energy of 20 GeV this ratio is about 1]. For zenith angles larger than 10° we have more events with A=0° than from other azimuthal direction.

Table 1: List of simulations and used input parameters (Z, A).

Z (°)	**A** (°)	**K** (°)	**N**
10	0	42.06	8050
	90	52.73	7685
	180	62.06	7239
20	0	32.06	8428
	30	35.77	8151
	60	44.55	7649
	90	54.71	6895
	180	72.06	6631
30	0	22.06	8295
	30	29.08	7764
	60	43.14	6768
	90	57.83	6161
	180	82.06	5594
40	0	12.06	7772
	30	24.49	6226
	60	43.57	5111
	90	61.90	4667
	180	89.94	4455

Two general statements are quite clear (see Table 1):

- If the azimuth angle (and also K) increases, the number of events decreases.
- If the zenith angle increases the differences become more pronounced.

We are interested in azimuth range from 0° to 90° which is related to interesting region of the sky. In our convention the A=0° means the shower points to the magnetic North, A=90° correspond to the cascade points to the West.

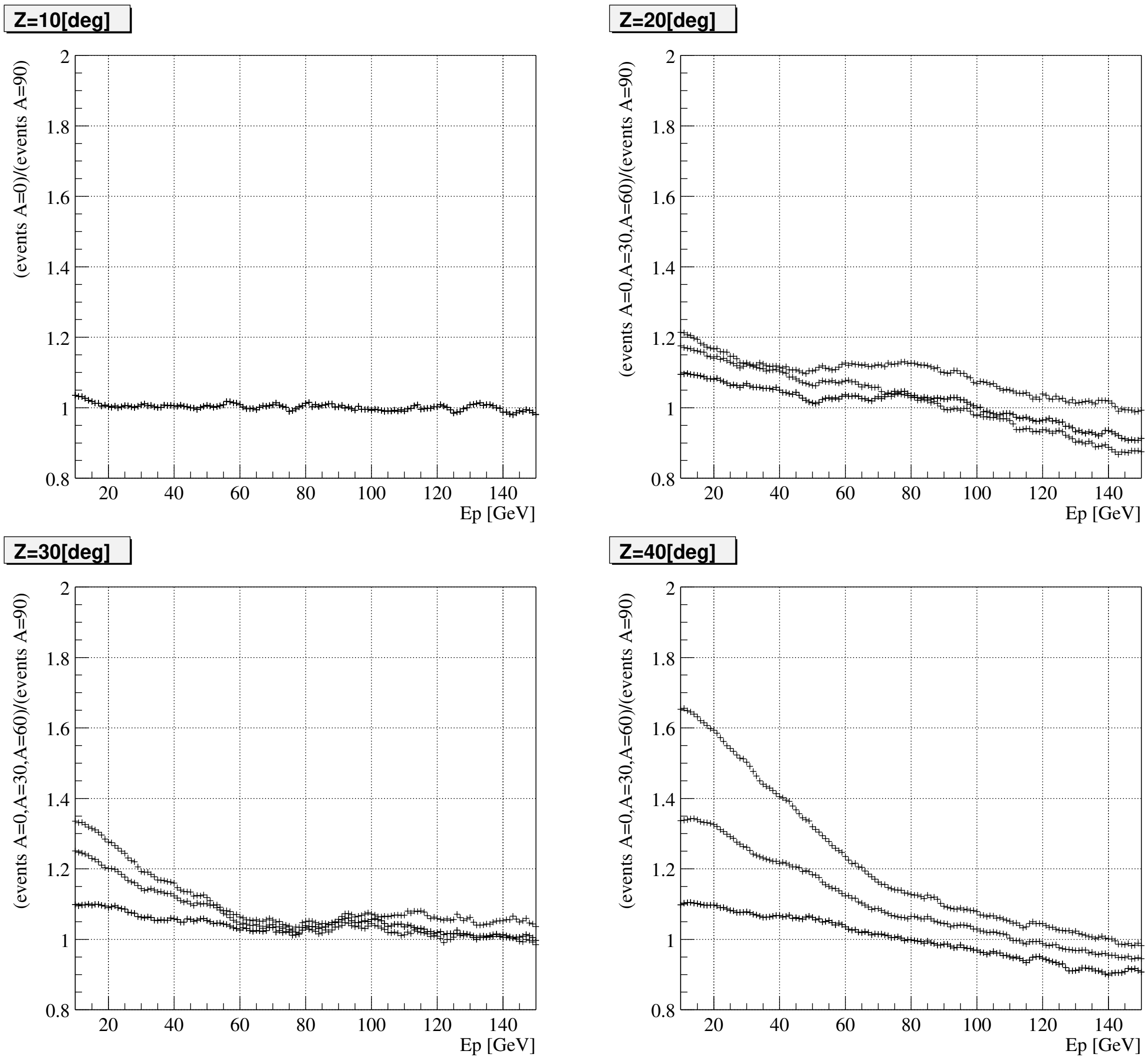


Figure 2. For Z=10° line show ratio of the number of events for A=0° and E≥E_p which pass "Hillas parameters calculation trigger" to the number of events with A=90° and E≥E_p which pass the same conditions (upper left plot). For Z=20°, 30°, 40° this same ratio is shown from top to the bottom (A=0°, A=30°, A=60°, respectively).

We have tested a few methods how to "correct" the data to make them "independent" on the azimuth angle and eventually we developed following algorithm:

- Reduce the signal at each pixel by the constant fraction **W** for each event.
- Make the standard cleaning.
- Check if it is possible to calculate Hillas parameters for the changed event -if it does not passed this "trigger" the event is rejected.

The output of the aplication of this procedure is present in Figure 3.

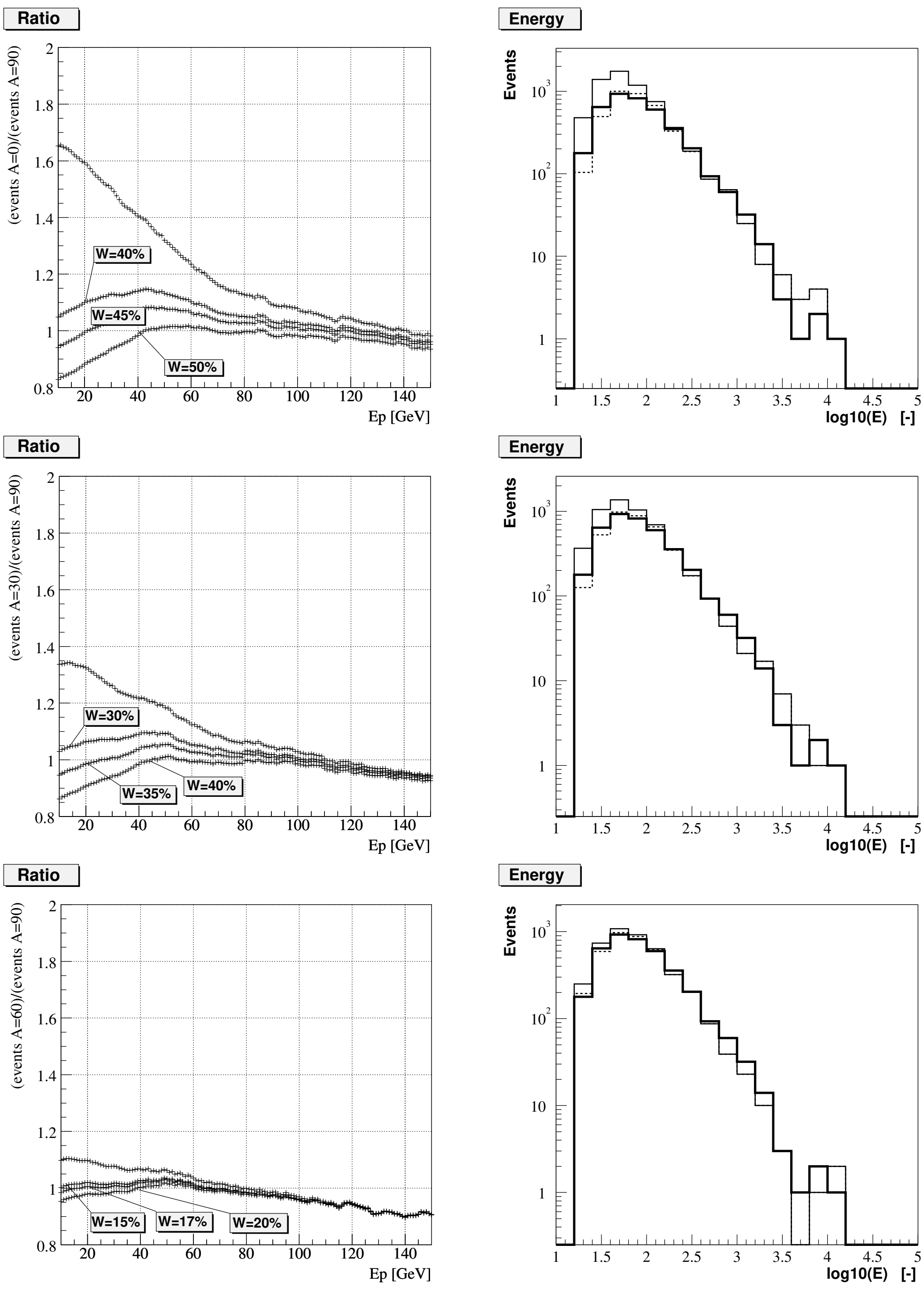


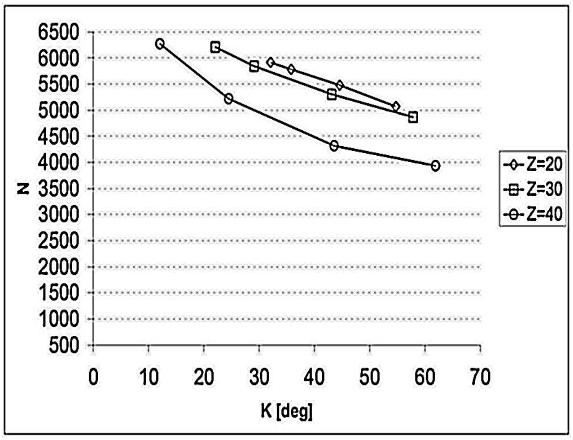
Figure 3. Examples of the results for the zenith angle Z=40°. On the left pictures the ratio of number of events for chosen A (0°, 30° or 60°) to the number of events for A=90° is seen. Lines show situation before and after (3 lines with marked W factor) our procedure. On the right figures are energy distributions of the events corresponding to the left figures. There are 3 figures with chosen A (0°, 30°, 60°). The thin solid line is for energy distribution before our procedure, dotted line after that with W=45%, 35%, 17% respectively.

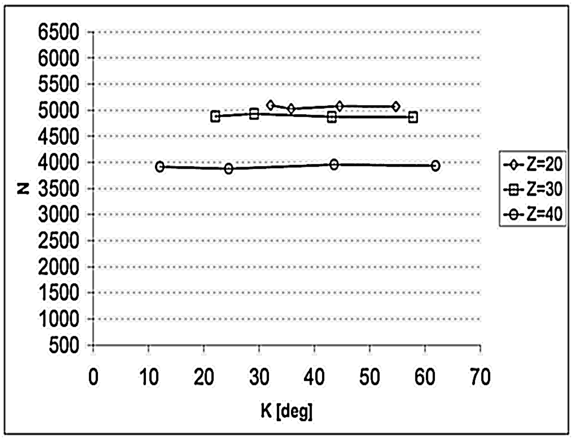
According to results of the Madrid group (TDAS 99-12) we expect that the diminishing of the event signal in each pixel can mimic the influence of Earth magnetic field. We are trying to find out if there exists the one reduction factor (for given Z and A) which applied to the data gives energy spectrum of the "trigered" events similar to the one for the same zenith angle Z and the azimuth angle A=90°. We can see in Figure 3 that do some extent this is possible. Of course such simple procedure can not give perfect results but due to its simplicity it can help with the data analysis. The reduction factors found (in fact by eye, more sophisticated methods were not used here (see Figure 3)), which are satisfactory are given in the Table 2.

Table 2: The best (see text) reduction factor values **W(%)**.

Z (°)	**A** (°)	**K** (°)	**W** (%)
20	0	32.06	30
	30	35.77	30
	60	44.55	20
30	0	22.06	35
	30	29.08	30
	60	43.14	20
40	0	12.06	45
	30	24.49	35
	60	43.57	17

It is worth to mention that this method is working on all MC samples. In the Figure 4 there is shown the number of events surviving the cleaning and Hillas parameter calculation as a function of the angle K without (left plots) and with our procedure applied (right graphs). Three rows of pictures correspond to energy cuts 20 GeV, 50 GeV and 100 GeV.





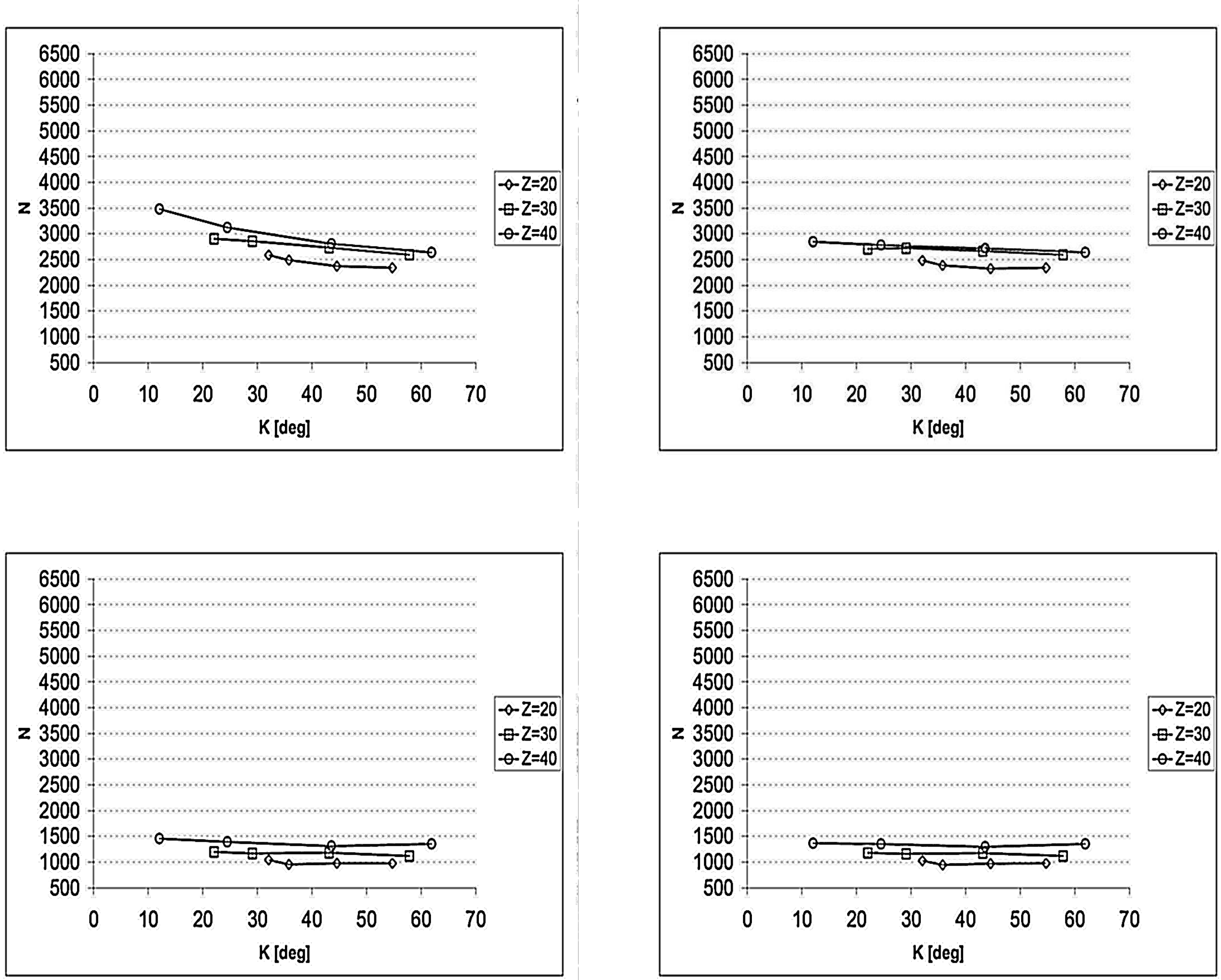


Figure 4. The number of the events surviving standard image cleaning and Hillas parameter calculation as a function of the angle between the shower axis and Earth magnetic field. Three rows of pictures correspond to energy cuts 20 GeV, 50 GeV and 100 GeV. The left panel represents raw simulated data, the right panel data corrected by the proposed procedure.

It is clear that the dependence on the angle K (between the shower axis and the Earth magnetic field) which is seen in the left plots, vanishes when our procedure is applied (right plots). We have tried to find the dependence of the reduction factor on the telescope axis orientation. In the Table 3 and in the Figure 5 the values of W obtained for each simulated sample as a function of K are shown. The straight line shown there represents:

$$W_t = -0.97K + 59.2. \tag{1}$$

Additionaly we can see in Figure 6 an example the energy spectra of corrected MC data for both reduction factors token from Table 3 in one sample of events.

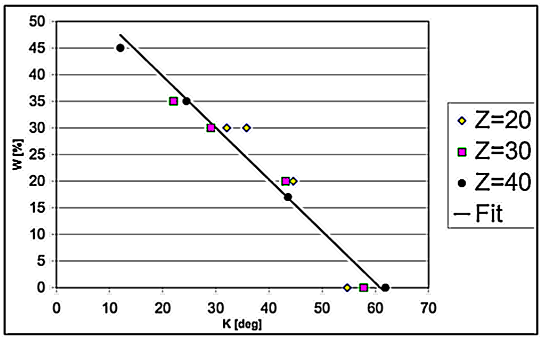


Figure 5. Reduction factors W, for different values of Z and A as a function of the angle K (between the shower axis and the Earth magnetic field). The line represent dependence given in Eq. (1).

Table 3: The reduction factor for all analysed data samples from equation (1) compared with values fitted directly to the each spectra from the Table 1 [in brackets].

A (°)	**K** (°)	$\mathbf{W}_t$(%) [**W**(%)]		
		Z=20°	**Z=30°**	**Z=40°**
0	32.06	28.0[30]		
30	35.77	24.4[30]		
60	44.55	15.9[20]		
90	57.7	6[0]		
0	22.06		37.7[35]	
30	29.08		30.9[30]	
60	43.14		17.3[20]	
90	57.82		3.0[0]	
0	12.06			47.4[45]
30	24.49			35.4[35]
60	43.57			16.8[17]
90	51.9			0[-1]

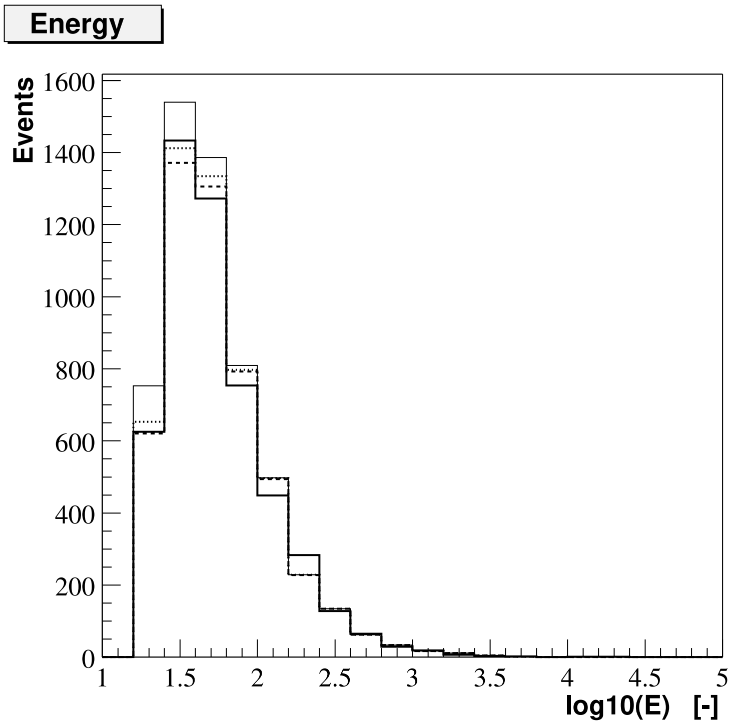


Figure 6. The energy spectra of events for Z=20°. Solid lines represent raw data: A=60° -thin line, A=90° -thick line. The data for the azimuth angle A=60° are corrected by our procedure with the reduction factor W=20% -dashed line and W_t=15.9% -dotted line.

2 Conclusions.

1. Energy spectra and distributions of the gamma cascades image parameters are different for the fixed zenith angle but different azimuth angles due to the influence of the Earth magnetic field on the shower development.

2. The reduction of signal imitates well (in first approximation) the effect of the Earth magnetic field.

3. Reduction factor values can be approximated as linear function of angle K (between the shower direction and the Earth magnetic field direction) -see Eq. (1).

4. The described method makes energy spectra of measured events for different azimuth angles similar.

5. Our method can be used to compare results of observations of the low energy for different MAGIC telescope orientation.