The DESY Cosmic Ray Trigger Hodoscope: Data Analysis and Simulation of Cosmic Ray Production with CORSIKA

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In this work data are analysed from the DESY Cosmic ray trigger hodoscope for the year 2005. The characteristics of the device, the event rates, and comparison with meteorological data are discussed. Furthermore, first results of simulations of cosmic ray production using the CORSIKA generator are presented.

1 Introduction

The investigations of cosmic rays plays an important role since the first detection at the beginning of last century (1912). In the last years the focus is directed on the origination and the acceleration mechanism up to ultra high energies.

At DESY Zeuthen a cosmic ray trigger hodoscope is installed which will be used in future by students and interested grammar school students to study cosmic particles [1].

One goal of this work is devoted to the analysis of the data obtained by the trigger hodoscope. We give a short review of software instruments and present results of the analysis of the 2005 data.

The other goal is the generation of cosmic air showers using the program CORSIKA. First results are presented in section 4.

1.1 Description of the hodoscope

The geometrical scheme of the trigger hodoscope is shown in figure 1. This detector is composed of three planes and four independent trigger segments per plane. The subdivision allows a better direction identification of the cosmic particles, as well as the decision whether one or several particles cross the detector. The distance between the upper and middle plane amounts to 0.7 m and between the middle and lower plane 2.3 m. The size of a plane is 1 m^2, of a segment 0.25 m^2.

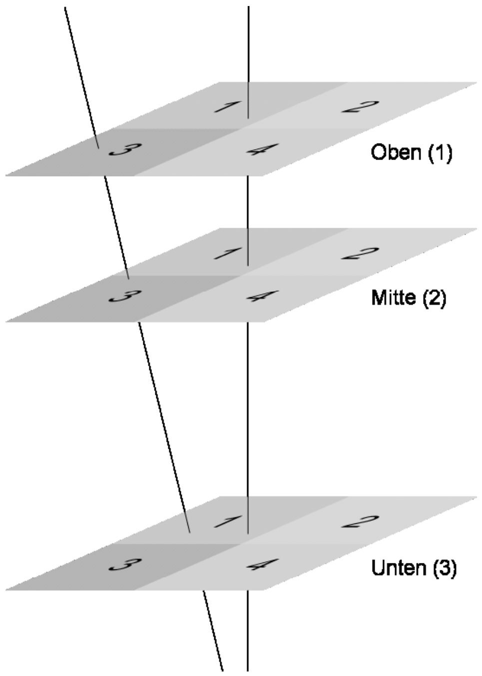

Fig. 1: *Trigger Hodoscope.*

The segments consist of scintillator plates red out by photosensors via plastic fibres. If a charged particle crosses a segment, it stimulates the atoms along his flight path. These radiate scintillation light which is guided via optical fibers to the photomultiplier. The photoeffect converts the photons in the cathode to photoelectrons which are accelerated and amplified then by the following dynodes. The electrical pulse gives a trigger signal. An electronical coincidence requires at least one trigger per plane.

1.2 Data files

To control the process of particles detection a special software was developed. It produces an data output file of the structure given in table 1. Activated segments are marked with 1 and inactive with 0. In the table the segments correspond to certain combinations (e.g., 11 - upper level, segment 1; 23 - middle level segment 3; 32 - lower level segment 2). A record contains the data of 24 hours and the data file every day begins automatically at 0 o'clock.

1.3 Motivations, physical possibilities, goal of the work with the Trigger Hodoscope

The trigger hodoscope allows an online observation of particles passing the Earth atmosphere. It is possible to collect a high statistics of cosmic particles and it also can be used for the monitoring cosmic rays, such as determination of current fluxes of detected particles, their possible type, tracks and primary directions, detection of air showers.

Other investigations which can be done with the Trigger Hodoscope require long-term data taking, for instance to find modulations of particle rates due to season variations, changes of the Earth magnetic field together with solar activity. But the last two items require high statistics.

2 Data analysis with ROOT

There are several possibilities to analyse data depending on the used software. First it is possible to use Microsoft Excel due to the table structure of the data file. But it is more useful to deal with the powerful ROOT program [2], which was developed for the analysis of high statistics data samples.

Defining the data as a set of objects, specialized storage methods are used to get direct access to the separate attributes of the selected objects, without having to touch the bulk of the data. It allows 1-, 2- and 3-dimensional histogramming, curve fitting, function evaluation, minimization, graphics and visualization classes.

It should be mentioned, that one can easily transforms text files to root files, which was done for the following analysis.

2.1 ROOT macro

The ROOT framework includes a so-called CINT (C++ interpreter) which allows a fast execution of macros since it removes the time consuming compile/link cycle. It also provides a good environment to learn C++. If more performance is needed the interactively developed macros can be compiled using a C++ compiler.

2.2 TreeViewer

A very flexible instrument for data analysis in ROOT is the TreeViewer. It is easy to run and it gives a pictorial view of the structure of rootfiles including those which have a difficult data hierarchy. For example there is possibility to construct multidimensional histograms, to test the amount of events according to logical conditions, and there are special options to write a TreeViewer session.

2.3 Carrot and the web application

Finally, it should be mentioned, that there is a widely developed web-oriented applications basing on the ROOT framework. It allows to run a ROOT macro on a web server. An example of this web-oriented application is Carrot. This is a module for the Apache web server which enables the use of C++ as an HTML-embedded scripting language as well as executing C++ macros [3]. In future the analysis of the trigger hodoscope data will be realized using this web application.

3 Results of the analysis of 2005 data

3.1 Total trigger rates

In figure 2 the total trigger rate per day is presented for the available 2005 data. In average about 16000 triggers per day and 11 per minute with at least one hit per plane are registered. The empty areas in the histogram are days where the detector did not work or where the data aquisition system had problems.

Tab. 1: *Structure of data file.*

Year	Month	Day	Time	11	12	...	34	Pressure	Temperature	Cloud
2005	09	09	00:00.0001	1	0	...	0	1015	18	4
2005	09	09	00:01.0023	0	0	...	1	1015	18	4
2005	09	09	00:03.7523	1	1	...	0	1016	18	4
2005	09	09	00:05.5681	1	0	...	1	1016	17	5
....										
2005	09	09	23:59.1198	0	1	...	0	1017	18	3

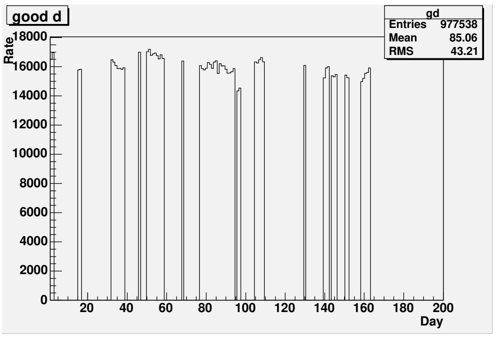

Fig. 2: *Good days distribution 2005.*

3.2 Trigger rates muon candidates

In the figure 3 one can see results of muon candidates detected in 2005, which are selected with the logical condition, that only one hit per plane is required.

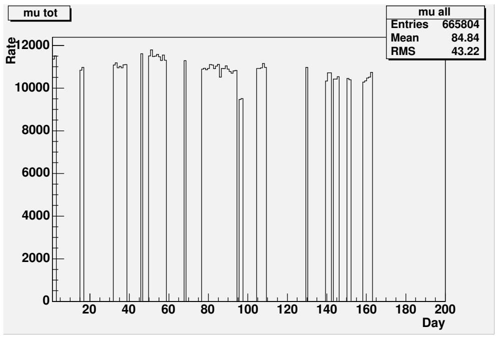

Fig. 3: *Total muon candidates time distribution in 2005.*

Furthermore, a special procedure to extract vertically moving muons is applied. In figure 4 these events are presented.

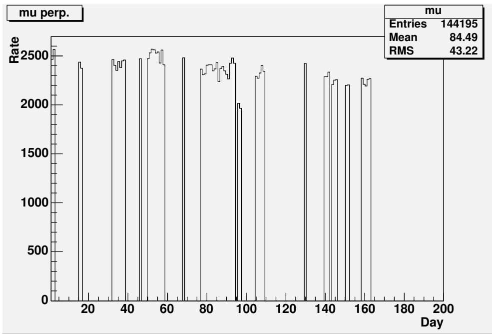

Fig. 4: *Candidates of vertically moving muons in 2005.*

3.3 Trigger rates shower candidates

Results for shower candidates on the period of observations is presented on figures 5. The logical condition which is used here requires triggers with three or four hits per plane.

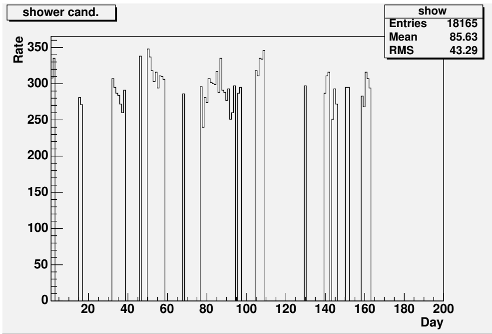

Fig. 5: *Shower candidates in 2005.*

3.4 Possible weather dependency of rates

One of goals of this work is to try to examine a possible weather dependency for muon and shower candidates. In figures 6 and 7 the pressure and the temperature distributions are shown, respectively.

Figures 8 and 9 show the distributions of pressure and temperature per day. One can see that

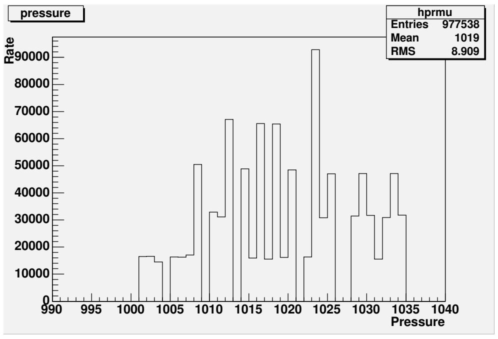

Fig. 6: *Quantity of events vs pressure.*

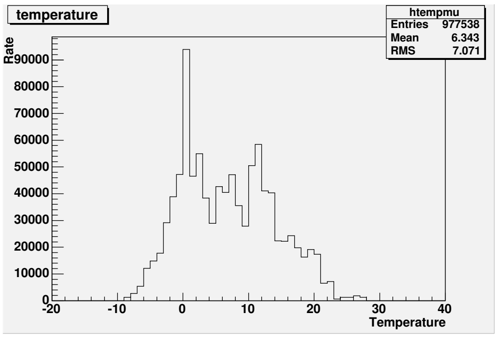

Fig. 7: *Quantity of events vs temperature.*

there is difficult to define some correlations between time distribution of events with temperature and with pressure.

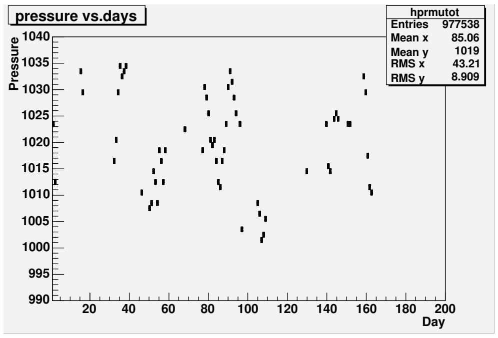

Fig. 8: *Pressure distribution for 2005.*

What can be the possible reason of increasing muon rate with high temperature we are looking for? The temperature increases in the summer and the density of the atmosphere is lower. But with a higher atmospheric density the probability for decays of pions and kaons in showers decreases, because of earlier interactions with other atmospheric particles. This means a lower production of secondaries including muons [4]. Whereas a lower density raises the fraction of decaying pions and kaons and thus the number

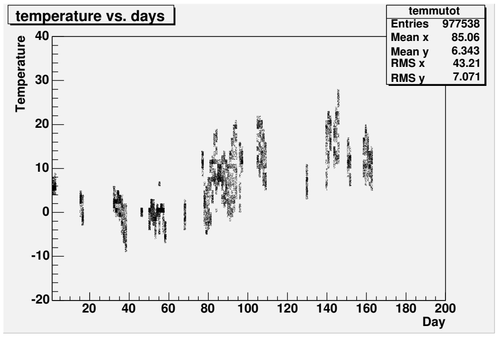

Fig. 9: *Temperature distribution for 2005.*

of incoming muons. According to these facts, we expect during the winter a decreasing number of muons and during the northern summer an increasing number.

Unfortunately there is with the present data no reliable basis to demonstrate such behavior.

4 Simulation of cosmic rays production with CORSIKA

4.1 General description and besic set-up

Analyzing experimental data on Extensive Air Showers (EAS) or planning corresponding experiments requires a detailed theoretical modelling of the cascade which develops when a high energy primary particle enters the atmosphere. This can only be achieved by detailed Monte Carlo calculations taking into account all knowledge of high energy strong and electromagnetic interactions. Therefore, a number of computer programs has been written to simulate the development of EAS in the atmosphere and a considerable number of publications exists discussing the results of such calculations. One of them is the CORSIKA generator.

CORSIKA (COsmic Ray SImulations for KAscade) is a program for detailed simulation of extensive air showers initiated by high energy cosmic ray particles. Protons, light nuclei up to iron, photons, and many other particles may be treated as primaries. The particles are tracked through the atmosphere until they undergo reactions with the air nuclei or - in the case of instable secondaries - decay. The hadronic interactions at high energies may be described by six reaction models alternatively.

It is important for our purposes that CORSIKA has several types of output files. One

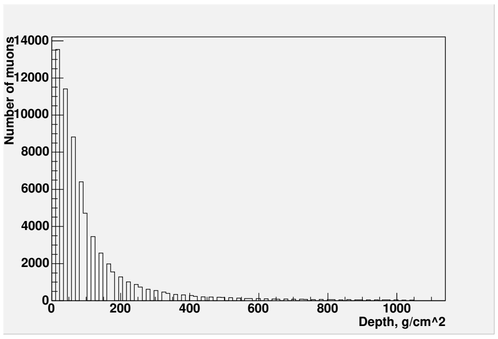

Fig. 10: *Longitudinal distribution of muons in winter.*

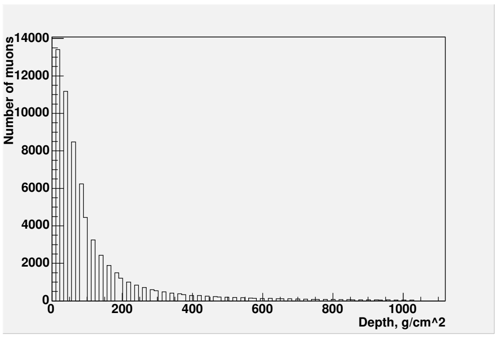

Fig. 11: *Longitudinal distribution of muons in summer.*

of them which is a detailed description of air shower produced by the program in binary code, which can be transformed into a ROOT file.

There are a lot of start parameters to set for the simulation [5]. We mark some of them. Files are generated for two periods in the year, for winter and summer. The respective parameters take into account the corresponding atmospheric model.

Moreover, for simulations of air showers it is important to determine the magnetic field of our planet. For this purpose with the special program Geomag (version 5.3 from NGDC, National Geophysical Data Center) the magnet field was calculated and used as input for for CORSIKA simulations. Geomag is based on the IGRF10 (International Geomagnetic Reference Field) model [6].

4.2 Results of CORSIKA simulations

We generated 15.000 events for each season and used vertically moving proton as primary particle [7]. The Energy region is chosen from $80GeV$ to $10^8 GeV$. The lower boundary corresponds to the possibility that muons arrive through at-

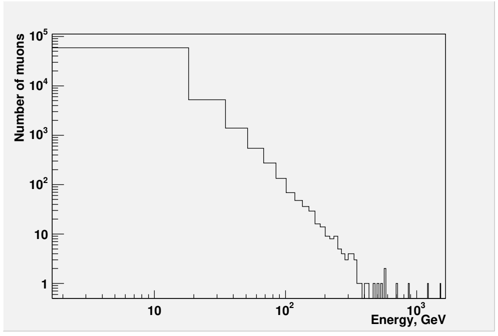

Fig. 12: *Energy of muons in winter.*

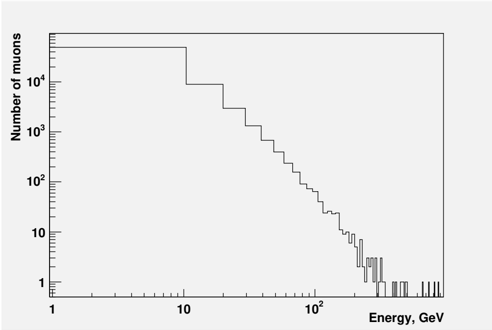

Fig. 13: *Energy of muons in summer.*

mosphere the observational level (60m). Below this energy it is quite difficult to detect muons because of the energy loss in the atmosphere. Muons loose about 2 GeV to ionization before reaching the ground [8].

The slope of the primary energy spectrum is equal to -2.7 according to the [9]. We set-up an energy threshold for hadrons, muons, electrons together with positrons and photons to the $0.3GeV$ $0.3GeV$ $0.07GeV$ $0.1GeV$ respectively. It can decrease calculation time by cutting detailed information about particles which are not interesting for this simulation.

The first series of simulation used the atmospheric model for the European area in a winter, February 23. The second in a summer, August 22. Simulations take into account both muons and antimuons.

The results of the simulation are shown in the following figures. In figures 10 and 11 typical longitudinal distributions for muons are presented in winter and summer period.

Figures 12 and 13 represent typical energy spectrum of atmospheric muons which reached the ground level in winter and summer respectively.

The pictures 14, 15 reflect the declination of

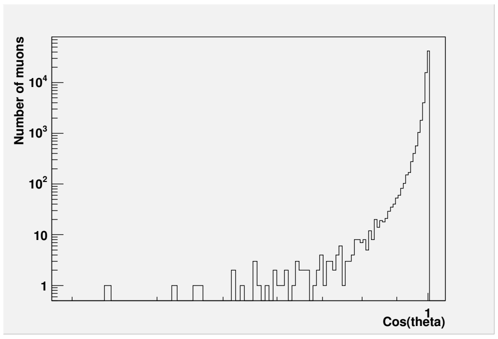

Fig. 14: *Angular distribution of muons in winter.*

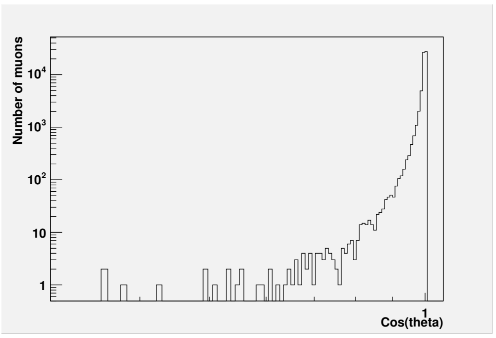

Fig. 15: *Angular distribution of muons in summer.*

muons from first primary protons direction. It is the cosine of the angle between vertical direction and the direction of a muon momentum.

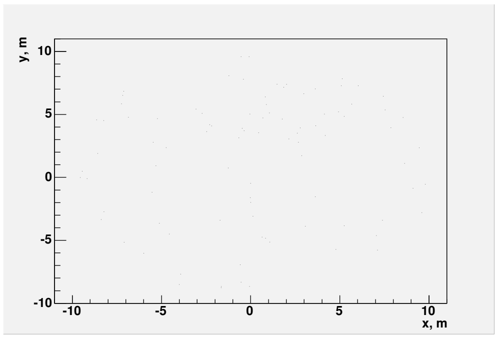

Fig. 16: *Spatial distribution of muons on the detector level,* $10^2 m^2$.

The following three figures (16-18) show the content of a shower on the three different levels of resolution. They are like a cut of the horizontal cross-section of a shower.

Figure 19 reflects the three dimensional distribution of muons in momentum space. One can see according to the energy spectra that muons are mostly collected in the low energy region near the beginning of the system of coordinates.

All this data show properties of generated

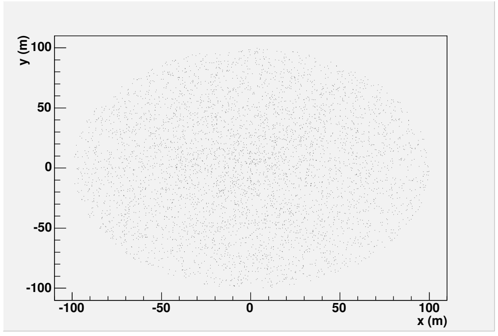

Fig. 17: *Spatial distribution of muons on the detector level,* $10^4 m^2$.

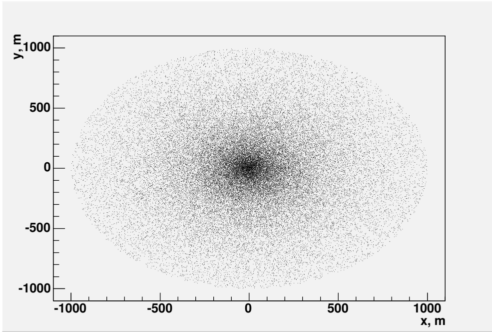

Fig. 18: *Spatial distribution of muons on the detector level,* $10^6 m^2$.

showers and also allow to calculate densities of muons on different areas as in figures 16-18 but numerically. Last one is represented on the Table 2 where the total number of muons per definite area is listed.

5 Conclusions

In this work we analyzed data from cosmic ray detector trigger hodoscope and produced series of simulations of air showers using the CORSIKA Monte Carlo generator. Main goals of the work were to find signatures for reconstructing events in the detector, to check some dependencies and correlations during the analysis of data and to generate corresponding events with the powerful simulator. As a result of working with a big amount of data we have found a lot of properties of incoming events. Muons and a shower candidates are also presented. We constructed weather dependence histograms of registered particles and found some proving to the expectation of increasing quantity of muons with high temperature in simulations. Although there is not enough statistics of measured data

Tab. 2: *Distribution of number of muons.*

Area, m^2	1	10	10^2	10^3	10^4	10^5
Summer	1	5	91	741	4874	20439
Winter	1	8	81	679	4371	18626

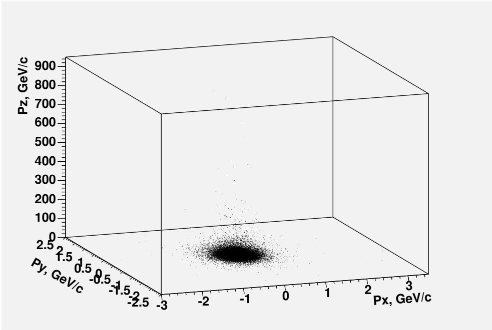

Fig. 19: *Distribution of muons in momentum space.*

to see this dependency.

We used CORSIKA and presented some interesting properties of proton generated showers for corresponding spectral region. In this part longitudinal, energy, angular and also spatial distributions of muons were shown.

At the end one should mention that the trigger hodoscope allows to check not only weather dependencies of cosmic rays rates but in long term perspective it can help to study effect of Earth magnetic field and solar activity.

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