Cosmic air showers in the ZEUS detector

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Abstract

The ZEUS detector has collected events originated from cosmic rays since 1999. The data were reconstructed and prepared available for analyses. During this time there was one period without the HERA beam (2002-2003) and with different cuts in taking the data than in a period when the Hera was running.

1 Introduction

An Air shower is an extensive (a few kilometres wide) cascade of ionizing particles and electromagnetic radiation produced in the atmosphere when a primary cosmic ray enters our atmosphere. The term cascade means that the incident particle, which could be a proton, a nucleus, an electron, or a positron strikes an atom in the air and produces many high energy particles, which in turn create more, and so on. The original particle having arrived with high energy, the products of the collisions tend also to move generally downward, while to some extent spreading sidewise. The overall effect, when the energy of the primary is high enough, is to produce a widespread flash of light due to the Cerenkov effect, and to excitation of air molecules. This can be detected with arrays of mirrors and photomultiplyers. The actual arrival of the cascade of particles can also be detected in many cases, also generally with detectors based on the Cerenkov effect.
Most galactic cosmic rays are probably accelerated in the blast waves of supernova remnants. This doesn't mean that the supernova explosion itself gets the particles up to these speeds. The remnants of the explosions, expanding clouds of gas and magnetic field, can last for thousands of years, and this is where cosmic rays are accelerated. Bouncing back and forth in the magnetic field of the remnant randomly lets some of the particles gain energy, and become cosmic rays. Eventually they build up enough speed that the remnant can no longer contain them, and they escape into the Galaxy.
Because the cosmic rays eventually escape the supernova remnant, they can only be accelerated up to a certain maximum energy, which depends upon the size of the acceleration region and the magnetic field strength.
However, cosmic rays have been observed at much higher energies than supernova remnants can generate, and where these ultra-high-energies come from is a big question. Perhaps they come

from outside the Galaxy, from active galactic nuclei, quasars or gamma ray bursts. Or perhaps they're the signature of some exotic new physics: superstrings, exotic dark matter, strongly-interacting neutrinos, or topological defects in the very structure of the universe. Questions like these tie cosmic-ray astrophysics to basic particle physics and the fundamental nature of the universe.

2 The ZEUS detector

The goal of the ZEUS detector (fig.1) is to determine with high precision the energies, directions and nature of single particles and particle jets created in the interactions of proton and electron or positron.
The ZEUS detector is located in the South hall of HERA. Its dimensions are
12 m x 10 m x 19 m and its total weight is 3600 tons.
The heart of the ZEUS detector is the uranium scintillator calorimeter (CAL) which measures energies and directions of particles and particle jets with high precision. This hermetically encloses the tracking detectors which measure the tracks of charged particles using wire chambers and which consist of: a vertex detector (VXD), the central drift chamber (CTD), forward (FTD) and backward (RTD) drift chambers and in the forward direction a transition radiation detector (TRD) to identify high energy electrons. These chambers are surrounded by a thin superconducting solenoid coll producing an axial magnetic field of 1.8 Tesla for determining the momenta of charged particles from track curvature. Energy not fully absorbed in the uranium calorimeter is measured in the backing calorimeter (BAC) which uses the 7.3 cm thick iron plates of the return yoke as absorber and proportional tube chambers for observing penetrating particles. Particles which are not absorbed in the substantial material of the uranium scintillator and backing calorimeter are typically identified as muons. Their tracks are measured before and after the iron yoke by limited streamer tube chambers (MUON). The muon momenta are determined by the deflections of their paths by the solenoid and by the iron yoke which is magnetized toroidally up to 1.6 Tesla by coppercoils. In the forward direction magnetized iron toroids instrumented with limited streamer tube and drift chambers measure very energetic muons (up to 150 GeV/c).
An iron wall equipped with two layers of scintillation counters (VETOWALL) is placed near the tunnel exit for detection of background particles produced upstream by the proton beam.
In the very forward direction the leading proton spectrometer is installed in the beam line to measure forward scattered protons.
In the direction of the electron beam photons and electrons are detected in the luminosity monitor.

The ZEUS detector can be used to collect and analyse cosmic events because of very high precision of time measurement. The selected events can be shown in a special program ZEVIS, which can reconstruct vertex, tracks, show which calorimeter or BAC towers were hit (red areas on the ZEVIS picture, fig.2,3)

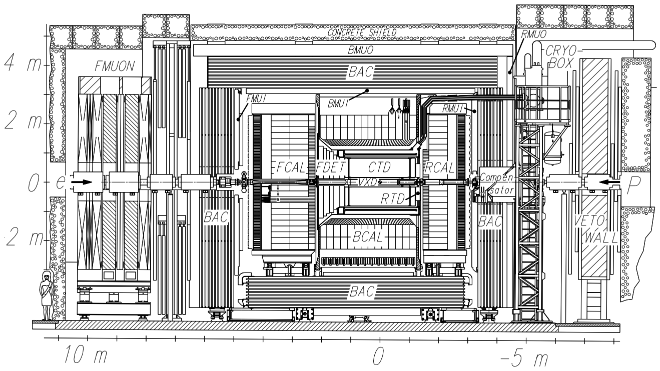

Figure 1: The scheme of the ZEUS detector

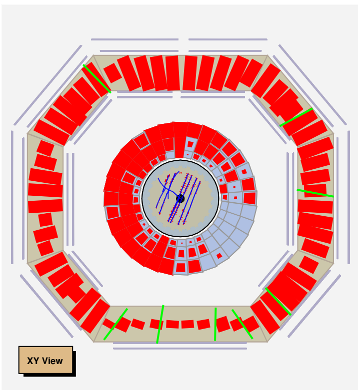

Figure 2: Picture shows XY view of UCAL and BAC with areas which were hit

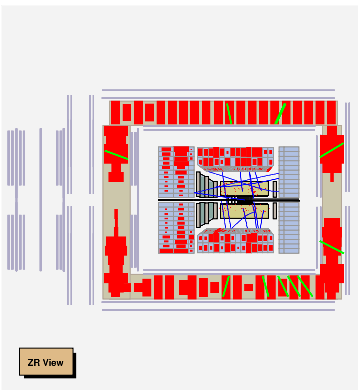

Figure 3: Picture shows ZR view of UCAL and BAC with tracks and areas which were hit

3 Analyses

During the period 1999-2007 there was one period without the HERA beam (2002-2003) and with the different selection criteria in taking data than in a period when the HERA was running. Without the HERA beam the trigger was choosing events with total energy, $E_{tot} > 15$ GeV. During the time when the HERA was running the selection criteria were based total energy, $E_{tot} > 90$ GeV.
My task was to compare the data from different periods of time. I prepared plots from a sample which consisted the data from 2002 (a period without the HERA beam) to investigate which events can be compared with events collected in 2000 (a period with the HERA beam). After study the plots I decided to make a basic selection criterion for data from 2002,

- total energy $E_{tot} > 60$ GeV or number of calorimeter cells, which were hit should be $N > 60$.

The plots were made in PAW. First three plots (fig.4) show diagrams of the total energy, total transverse energy and number of calorimeter cells which were hit, the fourth one consists an area based on the proposed selection criteria.

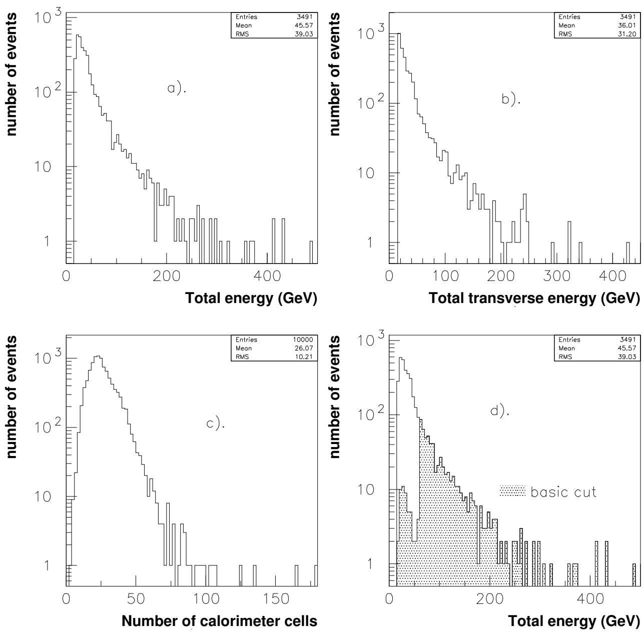

Figure 4: The sample from 2002: a). Total energy b). Total transverse energy c). Number of calorimeter cells (N) which were lighting d). Total energy with cut $E_{tot} > 60$ GeV or $N > 60$ put on it

After eliminating low energetic events I prepared the plots with more advanced selection criteria (fig.5), first to study only high energetic events (cut1) and second to eliminate background events (cut2). These criteria were used for two sets of data: with and without the HERA beam, for comparison.

- cut1 was defined as follows: $FcalE > 5$ GeV and $RcalE > 5$ GeV and $BcalE > 5$ GeV and $E_{trans} > 90$ GeV where
  $FcalE$ - energy deposited in a forward part of calorimeter; $BcalE$ - energy deposited in a barrel part of calorimeter; $RcalE$ - energy deposited in a rear part of calorimeter.

- cut2 was defined as follows: $\sqrt{(E_{emc}/E_{tot} - 0,5)^2 + (E_{trans}/E_{tot})^2} > 0,5$ where
  E_{emc} - energy deposited in electromagnetic part of calorimeter; E_{tot} - total energy measured in a calorimeter; E_{trans} - total transverse energy measured in a calorimeter.

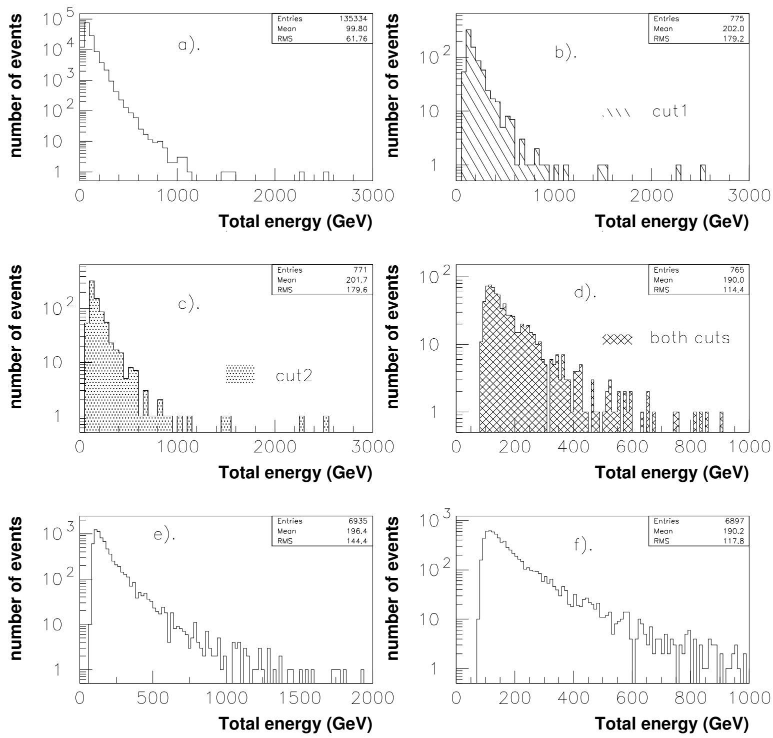

Figure 5: Plots made of data from 2002 (a,b,c,d) and data from 2000 (e,f): a). Total energy b). Total energy with cut1 c). Total energy with cut2 d). Total energy with both cuts e). Total energy f). Total energy with both cuts

These two sets of data were normalized to 1 (in area) and then compared (fig.6). They look similar. After comparison I did time differences between consecutive arrivals (fig.7,8) to investigate if there is some deviation from the expectation. In theory we expect that cosmic rays come to the earth randomly. I wanted to check if the events collected in the ZEUS detector are random. We expect that distribution of time between two measured events should be exponential distribution (fig.7,8 a.) Also it's interesting to check distribution of the short time intervals between two events. This was done for both parts of data: from 2000 and 2002 and it's shown on fig.7,8 b). The signal seems to be as expected for cosmic events.

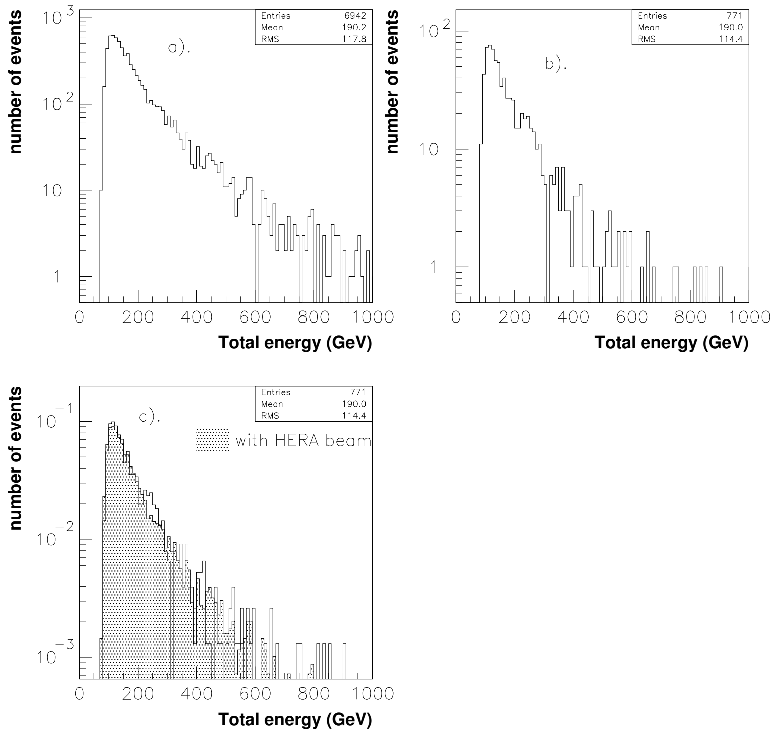

Figure 6: Distributions a). Total energy (data from 2000) b). Total energy (data from 2002) c). Both plots with normalization

The most interesting for us are those, when the detector collected many events. Usually we have few events per hour, in my research I have got the mean of all interesting events (these which were taken after cuts) about 13 events/hour.We expect also that we can register much more events if the time of the run is longer.

On the fig.10 we see that we had many short runs. This explains the fig.9 b). where we can see many events of very short length of the run and very small number of good events.

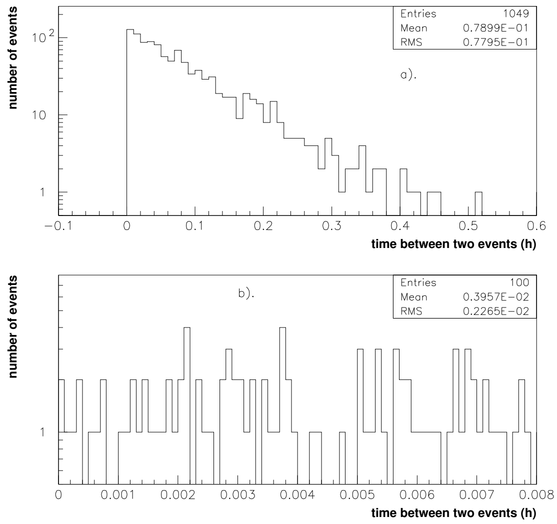

Figure 7: Distributions show time between two cosmic events in general (a.) and in a short period of time (b.). Data from 2002

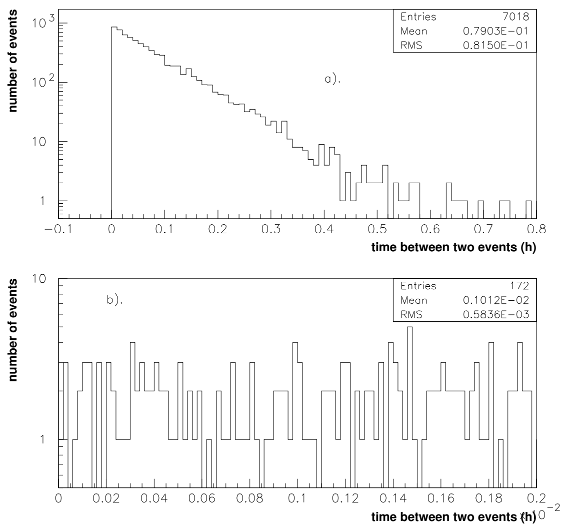

Figure 8: Distributions show time between two cosmic events in general (a.) and in a short period of time (b.). Data from 2000

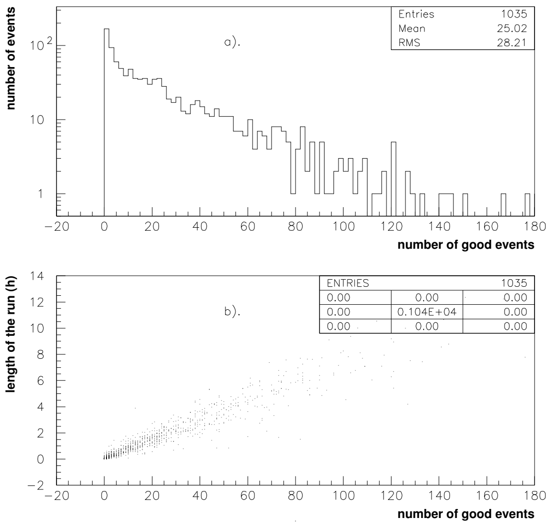

Figure 9: Distributions show a.) the number of good events which were taken b.) the length of the run in function with the number of good events. Data from 2000

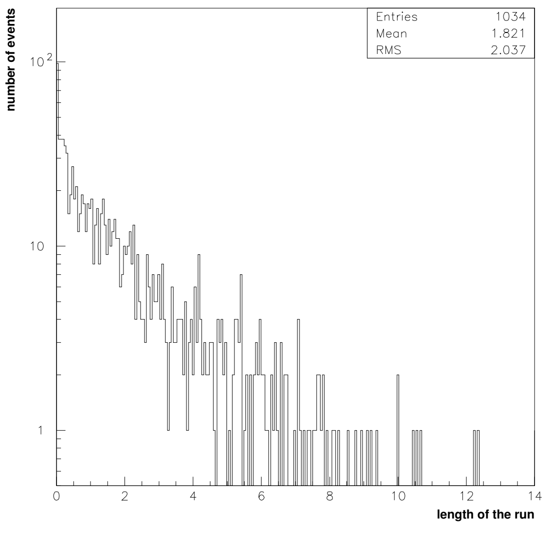

Figure 10: The length of the run

4 Summary

My task was to analyse the data from 2000 (during the HERA running) and 2002 (during the detector tests). I had to propose selection criterias for the data from 2002 to have a possibility to compare these two different parts of data. It was also important to chose only interesting, high energetic events, to eliminate noises as well as single cosmic events which, we decided, are not interesting for my research. To have a good possibility to compare these data, it was done special criterion which connected total energy with number of calorimeter cells which were hit. After this elimination of all low energetic events it were done another cuts, because in my research it was important to collect and than analyse only these events which can be originate from cosmic air showers. The chosen data (after cuts) were compared with a good result. Distribution of time between two registered events for both parts of data is a Poisson distribution also in a short period of time we didn't get any suspected signals. The number of good events registered in a detector is a linear function of the length of the run, like we expected. During taking the data there were many short runs, with only one good event, but we have no influence on that. These data will be analised in a broader spectrum.

5 Acknowledgments

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