KCDC User Manual for

Combined Data Analysis

KCDC - the **K**ASCADE **C**osmic Ray **D**ata **C**entre

Open Access Solution for the

KArlsruhe **S**hower **C**ore and **A**rray **De**tector (**KASCADE)**

KIT - University of the State of Baden-Wuerttemberg
and National Research Centre of the Helmholtz Association

Authors:	Jürgen Wochele, Donghwa Kang, Doris Wochele, Andreas Haungs, Sven Schoo
Address:	Karlsruhe Institute of Technology (KIT) Institute for Astroparticle Physics (IAP) Hermann-von-Helmholtz-Platz 1 76344 Eggenstein-Leopoldshafen
Internet:	kcdc.iap.kit.edu www.kit.edu

DOI:	https://doi.org/10.17616/R3TS4P
Version:	V-Cb.1.12
Last update:	2021-06-07

TABLE OF CONTENTS

1 INTRODUCTION

The *KCDC Manual for Combined Data Analysis* provides detailed explanation of data taken by the KASCADE/KASCADE-Grande Collaboration. The data already published in KCDC have been reanalysed by means of a modified data analysis software and made publicly accessible with the KCDC Project Internet Application.

In this manual, we restrict ourselves to describing the changes in the combined analysis compared to the previously published data, which mainly concerns data selection, and data analysis in Chapter 2, and the published quantities as described in chapter 3.

As the detector components and the data acquisition system are already described in detail in the 'KCDC User Manual', we kindly ask the user to get the details from there.

Moreover all technical details concerning the handling of the KCDC Data Shop, and the plugins like 'Publications' or 'Spectra' are not covered here.

The KCDC-Team is quite aware of the fact that not all details concerning data acquisition and data analysis can be described in this manual.

1.1 KCDC - THE KASCADE COSMIC RAY DATA CENTRE

KCDC is the 'KASCADE Cosmic Ray Data Centre', where via a web-based interface data of a astroparticle physics experiment will be made available for the interested public.

The KASCADE experiment, financed by public money, was a large-area detector for the measurement of high-energy cosmic rays. These charged particles (fully ionised atomic nuclei) are accelerated in active cosmic objects, propagated through the intergalactic and interstellar medium of the Universe, and reach our Earth for energies above 10^{14} eV with a rate of less than one per minute and square meter. Hitting our Atmosphere, they subsequently interact with nuclei and generate a cascade of millions of secondary particles, which partly reach the Earth surface and can be detected. This phenomenon is called an extensive air shower: EAS. With an array of particle detectors, this secondary cosmic radiation of individual EAS can be detected and the parameters of the impinging primary particle reconstructed. In a second step, the energy spectrum, elemental composition and the arrival distribution of the primary cosmic rays are investigated and by this, the astrophysical question to the origin of cosmic rays is studied. KASCADE was extended to KASCADE-Grande in 2003 to reach higher energies of primary cosmic rays where the rate decreases to less than one per day and square meter. KASCADE-Grande stopped finally the active data acquisition of all its components end of 2012 and is already decommissioned. The international collaboration of the experiment, however, continues the detailed analysis of nearly 20 years of data.

Moreover, with KCDC we plan to provide the public the edited data, i.e. the reconstructed parameters of the primary cosmic rays measured via the detection of EAS with the KASCADE-Grande experiment, via a customized web page. The aim of this particular project is the installation and establishment of a public data centre for high-energy astroparticle physics. In the research field of astroparticle physics, such a data release is a novelty, whereas the data publication in astronomy has been established for a long time. But, due to basic differences in the measurements of cosmic-ray induced air showers compared with astronomical data, KCDC provides the first conceptional design, how the data can be treated and processed so that they are reasonably usable outside the community of experts in the research field. The first goal of KCDC is to make to the community the data from the KASCADE experiment available to external users.

In November 2013, we published in a first step 15 parameters of reconstructed and calibrated data, which we thought are necessary to do simple astroparticle physics analysis, e.g. the time, arrival direction and energy of events, etc.

With every new release, we added more data sets or more quantities to enable the users to perform more complex and more sophisticated analysis with the KASCADE data. As the preparation of the data for public usage is rather time consuming and the KCDC team is rather small, we ask you to be a little patient if not all parameter you would like to do analysis with, can be made available at once.

Information on the available KASCADE Simulations can be found in the 'KCDC Simulations Manual'.

1.2 KCDC Motivation

The aim of Astroparticle Physics is to investigate the nature of the Cosmic Radiation manifesting in many ways. In various air shower experiments all over the world the cascades of particles are detected, generated in interaction processes between the particles of the Cosmic Radiation and the atmosphere of the earth. As the Air Showers consist of a huge number of particles, which are spread over a vast area, big detectors are required to measure a number of parameters of these showers. The combined analysis of observations of various components of the cosmic radiation like charged particles, gamma rays and neutrinos is widely known as "Multi Messenger Astroparticle Physics". From this presently as "hot topic" classified field we hope to gain new and exciting information to extend our knowledge of the origin and transport of what we understand as Cosmic Radiation.

Necessary to achieve such a challenging aim is a free access to the data of various experiments measuring cosmic radiation by different methods and techniques. This is likewise interesting for the community of scientists as well as for all public interested in this topic.

A first step in this direction is to provide the data as well as the tools to analyse the data measured with the KASCADE / KASCADE-Grande Experiment for public use. This project is called the KASCADE Cosmic Ray Data Centre, "KCDC".

Our motivation is based on three ideas:

The idea of open data as it is laid down in the "Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities" from 22.10.2003. There we read:

"Our mission of disseminating knowledge is only half complete if the information is not made widely and readily available to society. New possibilities of knowledge dissemination not only through the classical form but also and increasingly through the open access paradigm via the Internet have to be supported. We define open access as a comprehensive source of human knowledge and cultural heritage that has been approved by the scientific community."

and

"In order to realize the vision of a global and accessible representation of knowledge, the future Web has to be sustainable, interactive, and transparent. Content and software tools must be openly accessible and compatible."

The Helmholtz Alliance and the KIT plead for further use and for re-examination of the measured data based on this declaration.

Furthermore, KASCADE was financed by taxpayer's money, which implies that the collected data are public property. We want to prepare our data in a way that the public will be able to access and use the data.

The data have to be preserved for future generations in a way that they should not only be able to re-perform all analysis steps and conclusions which led us to our widely approved results manifested in a lot of international publications, but also to be able to use the data far beyond the lifetime of the experiment which has in fact been shut down already end of 2012.

This approach is new in Astroparticle Physics as well as in the neighbouring fields like Nuclear Physics and High Energy Physics, but well known from Astronomy. Therefore, it is our aim to provide a consistent 'bundle' of hard- and software applicable for cosmic ray data. KCDC will handle questions like calibration of the raw data, applied quality cuts, data formats but also internet access via a web portal and the associated questions like legal rights and so on from the very beginning.

Because of the huge amount of available data, it is not feasible to offer all data in a 'tar ball' for download. Moreover, we offer a way to apply reasonable selection cuts to reduce the variety of data and parameters adapted to the requirements of the analysis the user intends to perform.

We try to achieve this by means of a flexible web portal providing a modern software solution for publishing the KASCADE / KASCADE-Grande data for a general audience based on open source software. KCDC as a WEB portal offers software as a service without installation by the user with the advantage of a worldwide access via web browsers to data and processing facilities. We also supply meta information on the detectors and the available data.

Moreover, we provide example analysis to encourage teachers and pupils to use our data for their first step into the exciting field of cosmic radiation and astroparticle physics.

1.3 KCDC Data Overview

The list provided is intended to give a brief overview of the data from the KASCADE-Grande experiment that has been published to date with the latest release PENTARUS.

DataShop	Detector	Component	Nr of Events
KASCADE	KASCADE-Grande	array	433,209,340
		grande	35,310,393
		calorimeter	100,655,080
		lopes	3,058
		general	433,209,340
COMBINED	KASCADE-Grande	combined	15,635,550
		lopes	1,430
		general	15,635,550

1.4 COMBINED Naming Conventions

The cosmic ray experiment of which we are publishing the data via the KCDC web portal, started under the name '**KASCADE'** and consisted of 252 detector stations placed on a 100x100m² area with a hadron calorimeter in its centre. It was extended by 37 additional detector stations distributed over an area of 700x700m² running under the new name '**KASCADE-Grande'**. These two detectors were analysed up to now separately. With the combined data analysis presented here, it no longer makes sense to talk of separate detectors, even though input data and applied cuts are different. When we talk about **KASCADE** and **GRANDE**, we always mean the two detectors. **COMBINED** must be regarded as a synonym for the 'new virtual detector' that emerged from the combined data analysis of both.

1.5 THE KCDC TEAM

Fig. 1.3.1 *The KCDC-Team*

2 THE COMBINED DATA ANALYSIS

2.1 KASCADE-GRANDE SETUP

The KASCADE-Grande detector system and the data acquisition was described in detail in the 'KCDC User Manual', accessible via the KCDC web portal.

Shortly, the experiment consisted of four major detector components (see fig 2.1.1) of which two detectors were now combined for a common analysis, the original KASCADE Array and the GRANDE Detector Array.

The KASCADE Array consisted of 252 detector stations housing separate electron and muon detectors and a second array called GRANDE with 37 detector stations for electron detection, which extends the effective KASCADE array area from 200x200 m² by a factor of 10.

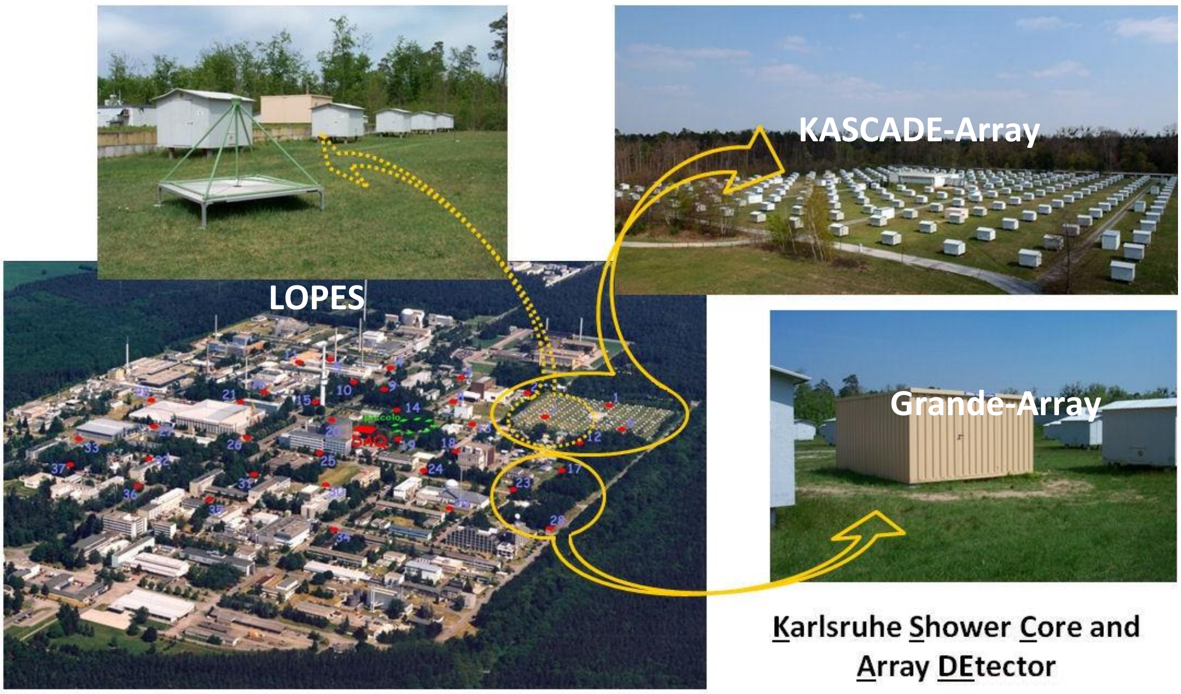


Fig. 2.1.1 *Location of the KASCADE detector arrays*

Besides the COMBINED data we publish in this Data Shop, the matching data sets from the Radio LOPES experiment (**LO**far **P**rototyp**E** **S**tation), distributed over the KASCADE detector array are made available.

2.2 WHY COMBINED?

Until now, data taken by KASCADE and its extension KASCADE-Grande have been analysed independently of each other, although the GRANDE data analyses used the shielded detectors of KASCADE for the reconstruction of the total number of muons.

Treating both detectors as one has several advantages over the standalone analysis. For events where the shower core is located within the KASCADE array, the main advantage is the increased distance range in which sampling points are available. Because of this, the reconstruction of showers induced by primaries with higher energy is possible.

For GRANDE the main benefit is the availability of 252 additional detector stations among which three GRANDE stations are located. This should result in a more accurate reconstruction of the shower observables.

The aim of the combined analysis was to utilize this improved reconstruction to get one single, consistent spectrum in the energy range 10^{15} eV to 10^{18} eV. The focus is on the mass composition, which is one of the most important sources of information needed to restrict astrophysical models on the origin and propagation of cosmic rays. With the improved reconstruction of the shower observables, a study of the elemental composition of high-energy cosmic rays is possible in a more detailed way.

2.3 COMBINED SHOWER RECONSTRUCTION

The main goal for the shower reconstruction using the combined analysis is to extract electrons and muons from the energy deposits as measured in KASCADE and GRANDE. The procedure follows the one developed for the KASCADE standalone analysis. But now, the data sets from both detectors are treated as a single data set in KRETA.

The reconstruction is performed separately for events located in KASCADE and in GRANDE, although in both cases all the detectors of the two arrays are used and the same procedure is applied to all events. The reason to distinguish between events where the shower core is located in KASCADE or in GRANDE is that the accuracy of the reconstruction of N_e and N_μ is different for events located in the respective other array. In addition, the muonic component is only measured by the KASCADE detectors; hence, a different part of the muonic component is sampled for events located in KASCADE compared to events located in GRANDE.

The reconstruction procedure is tuned in a way that if only one detector has found a shower core then the corresponding results on position, direction and shower size are taken. In case of both arrays have found a core, the KASCADE core is taken, if the reconstructed GRANDE core lies within KASCADE, else the GRANDE results are taken. As the applied cuts are coupled to the shower core position, we will have to differentiate in terms of cuts (see chapter 2.4).

If the reconstruction procedure would be tuned independently of the shower location, the differences in the reconstruction would be effectively ignored for events located in KASCADE, because the fiducial area covered by KASCADE is ten times smaller than the area selected for KASCADE-Grande. Nevertheless, by combining the two detectors, the quality of the reconstruction is improved for both sets of events and the corresponding results can still be merged once the composition of cosmic rays has been reconstructed, which will make a correction for the known reconstruction effects possible.

2.4 Applied Analysis Cuts

Some selection criteria have been applied to ensure good quality of the reconstructed quantities.

Bad Runs cut: measurement periods during which problems with either the KASCADE or the GRANDE detectors occurred or where at least one of them was inactive are excluded.

ANKA cut: the synchrotron radiation facility ANKA at KIT-Campus North was inducing fake events during beam injection or beam stops. Events recorded within these time windows have been identified and excluded.

As the cuts mentioned above are only applied to measured data, the following selection criteria are applied to both, measured and simulated events.

Area cut: in order to avoid border effects at the edges of the detector arrays, a smaller fiducial area was chosen compared to what is covered by the detectors, shown in fig. 3.4.1, slightly different for measured data and for simulations mostly due to the synchrotron radiation source ANKA.

Zenith Angle cut: the angular resolution drops significantly above about θ>30 °, caused by the fact that the reconstruction algorithm for COMBINED has been fine-tuned to zenith angles below 30°.

As described above, some cuts applied depend whether the reconstructed core position lies within KASCADE or GRANDE.

Age cut: for events located in KASCADE, the age parameter was chosen to be within the range from 0.2 to 1.48. For events within GRANDE, the range was chosen to be 0.15 to 1.48.

N_e cut: for events with the shower core within KASCADE a minimum $\log(N_e) = 3.2$ is required which is well below the threshold of full efficiency. For GRANDE a minimum $\log(N_e) = 4.8$ electrons is used.

N_μ cut: a loose cut on the number of muons is defined as $\log(n_\mu) = 3.0$ for all events with the shower core either within KASCADE or within GRANDE.

Station cuts: for GRANDE are at least 12 detector stations with valid time information necessary to generate a reliable time fit to get the shower direction. Additionally for GRANDE at least one of the overlapping trigger hexagons had to be triggered. For events located in KASCADE, at least six detector stations must have been triggered.

Core Distance cut: the shower core is reconstructed in each of the three iteration levels within the reconstruction program KRETA. The maximum distance between these core positions must be less than 70 m.

More Complex cuts: there are some more complex cuts used to remove non-physical nonsense. These cuts are mostly derived from some two-dimensional plots of N_e, N_μ and Age.

3 COMBINED DATA IN KCDC

The measured air showers in KASCADE-Grande are analysed using the reconstruction program KRETA (***K**ascade **R**econstruction for **E**x**T**ensive **A**irshowers*), which reads the raw data, performs the calibration and reconstructs the basic shower observables, storing all the results in the form of histograms and vectors of parameters (ntuples).

The reconstruction procedure starts after the calibration phase and develops internally over three levels using an iterative process to come to the results.

Concerning the 'Combined Analysis' level 1 remains unchanged, the combination of the data is performed in analysis levels 2 and 3.

Based on data generation and data handling we distinguish between:

Measuring Data

Corresponding to data which are directly measured or reconstructed by the KASCADE analysis software like core positions and angles.

Calibration Data

Used to calibrate the data sets on an event-by-event basis like air temperature and air pressure.

Event Information

Used to characterise an event uniquely like run number and event time.

Quantity	Description	Unit	ID
Measuring Data			
Energy	first order reconstructed Energy	eV	E
Core Position X	location of the reconstructed shower core x-position	m	Xc
Core Position Y	location of the reconstructed shower core y-position	m	Yc

Quantity	**Description**	**Unit**	ID
Zenith Angle	reconstructed zenith angle with respect to the vertical	° *(degree)*	Ze
Azimuth Angle	reconstructed azimuth angle with respect to the north	° *(degree)*	Az
Electron Number	reconstructed number of electrons (fit)	*(number of)*	*Ne*
Muon Number	reconstructed number of Muons (fit)	*(number of)*	*Nmu*
Age	Shower shape parameter		*Age*
e/γ - energy deposits	Energy deposit in MeV / station	*(MeV)*	*EDeposit*
μ - energy deposits	Energy Deposit in MeV / station	*(MeV)*	*MDeposit*
Arrival Times	Arrival Times / station	*ns*	*Arrival*
Calibration Data			
Air Temperature	temperature on site at event time	*°C*	*T*
Air Pressure	air pressure on site at event time	*hPa*	*P*
Event Information			
Run Number	internal KASCADE counting number	*(number of)*	*R*
Event Number	internal KASCADE counting number	*(number of)*	*Ev*
Event Date	event date	*UTC*	*Datetime*
Global Time	event date time in seconds since 1.1.1970 (unix time)	*s*	*GT*
Micro Time	event time in 200 ns steps	*(number of)*	*M*
UUID	Universally Unique IDentifier	*(number of)*	*UUID*

The plots schown in this chapter are only examples, mostly based on a subsample of the data set published. So, applying user cuts either in the KCDC Data Shop or in your own analysis can change these spectra drastically.

3.1 SHOWER RECONSTRUCTION

The number of electrons and muons have to be extracted from the energy deposited in the KASCADE and GRANDE detectors. The procedure follows the one developed for the KASCADE standalone analysis.

The data set contains only a subset of the true number of air showers that hit the detector. This is partly due to the trigger efficiency, which means that not all low energetic showers trigger the data taking. In addition, the applied selection criteria remove events from the total data set based on the quality of their reconstruction. Hence, the combined trigger and reconstruction threshold has to be inferred. The threshold is defined in terms of the primary energy of the cosmic ray and corresponds to the energy above which all events of the original data set are still present in the final event sample.

The reconstruction is performed separately for events located in KASCADE and GRANDE, although in both cases all the detectors of the two arrays are used and the same procedure is applied to all events. The reason to distinguish between events located in KASCADE and GRANDE is that the accuracy of the reconstruction of N_e and N_μ is different for events located in the respective other array. In addition, the muonic component is only measured by the KASCADE detectors, hence, a different part of the muonic component is sampled for events located in KASCADE compared to events located in KASCADE-Grande. If the reconstruction procedure would be tuned independently of the location, the differences in the reconstruction would be effectively ignored for events located in KASCADE, because the fiducial area covered by KASCADE is ten times smaller than the area selected for GRANDE. Nonetheless, by combining the two detectors, the quality of the reconstruction is improved for both sets of events and the corresponding results can still be merged once the composition of cosmic rays has been reconstructed, which will make a correction for the known reconstruction effects possible.

The reconstruction of the shower is organized in three steps. **Step one** is used to get a first estimate of the particle numbers, arrival direction, and the position of the core. The latter is achieved by using the centre of gravity of the signals of the non-shielded scintillation detectors. Assuming a plane shower front, the arrival direction is estimated, while the geometrically weighted signals of the non-shielded and shielded detectors are used to retrieve the starting values for N_{ch} and N_{μ}, respectively. For steps two and three, the energy deposits have to be transformed into particle numbers. This is done using a lateral energy correction function, which describes the average energy deposited per charged particle taking into account the size of the shower obtained in the previous step and the distance of the station to the shower core.

In **step two**, the arrival direction is improved by fitting a conically shaped shower front to the arrival times of the first particles measured with the non-shielded detectors. The core position, N_{ch} and the so-called shower-age, i.e. the slope parameter of the function are then obtained by fitting an NKG-like lateral density function to the particle densities measured at the non-shielded detectors. The original NKG function has been derived analytically for e/γ induced showers describing the lateral distribution of the electromagnetic particles. However, the original function cannot describe the electromagnetic component of hadron-induced showers well. This is commonly attributed to the fact that the electromagnetic component of a hadron-induced shower is a superposition of a large number of electromagnetic sub-showers. Therefore, a different parameterization of the lateral density function has to be used.

The reconstruction of N_{μ} is performed simultaneously, therefore, the muon lateral density function is known at the beginning of **step three** and its information is included in the fitting procedure for the non-shielded detectors resulting in the total number of electrons at observation level. The number of muons is obtained in a similar way. The transformation of energy deposits takes into account a N_e dependent probability of electrons, photons or hadrons passing the shielding. These particles falsely counted as muons dominate the signal for stations with a distance within 40m of the core, therefore, these stations are ignored for the fit. In addition, the NKG-like function is known to deviate from the true muon distribution towards larger distances to the shower core, hence, instead of using the total number of muons, the truncated number of muons is used, which is the result of the integration of the fitted lateral density function in the range from 40 - 200m, i.e. where the KASCADE detectors provide sampling points for the fit. In addition, because of the low muon densities, the shape parameter, i.e. the slope of the lateral density function is fixed to a value derived using simulations. This value changes depending on the shower size. The only remaining free parameter is, therefore, the total number of muons.

3.2 NUMBER OF ELECTRONS AND NUMBER OF MUONS (NE, NMU)

In KASCADE-Grande, the energy deposits of electrons and muons at ground level are measured, as well as their arrival time in every single detector station of KASCADE and GRANDE. From these measurements, the arrival direction of the shower, its impact point on ground (shower core) and the total number of electrons and muons in the shower, i.e. the electron and muon shower sizes are reconstructed. Reconstruction is performed in three so-called levels.

The reconstruction of Ne and Nμ follows the same procedure as described in the KASCADE shower reconstruction (see 'KCDC User Manual'). However, this analysis is based on the combined information from both detectors instead of KASCADE only and in case of the reconstruction of N_e a slightly different parameterization for the NKG-like function which is α = 1.6, β = 3.5, and r_0 = 20m at level 2 and α = 1.6, β = 3.4, and r_0 = 30m at level 3.

$$\varrho_e(r) = C(s) \cdot N_e \left(\frac{r}{r_0}\right)^{s-2} \left(1 + \frac{r}{r_0}\right)^{s-4.5}$$

with

$$C(s) = \frac{\Gamma(\beta - s)}{2\pi r_0^2 \Gamma(s - \alpha + 2)(\alpha + \beta - 2s - 2)}$$

In addition, the size dependent parameterization of the shape of the muon lateral density function has been updated and N_μ has been obtained without applying the truncation. The combination results in some advantages compared to the standalone. The parameterization for the reconstruction of muons is α = 1.5, β = 3.7, and r_0 = 420m.

Figures 3.2.1 and 3.2.2 show the N_e and N_μ distributions of the combined analysis in a log-log scale.

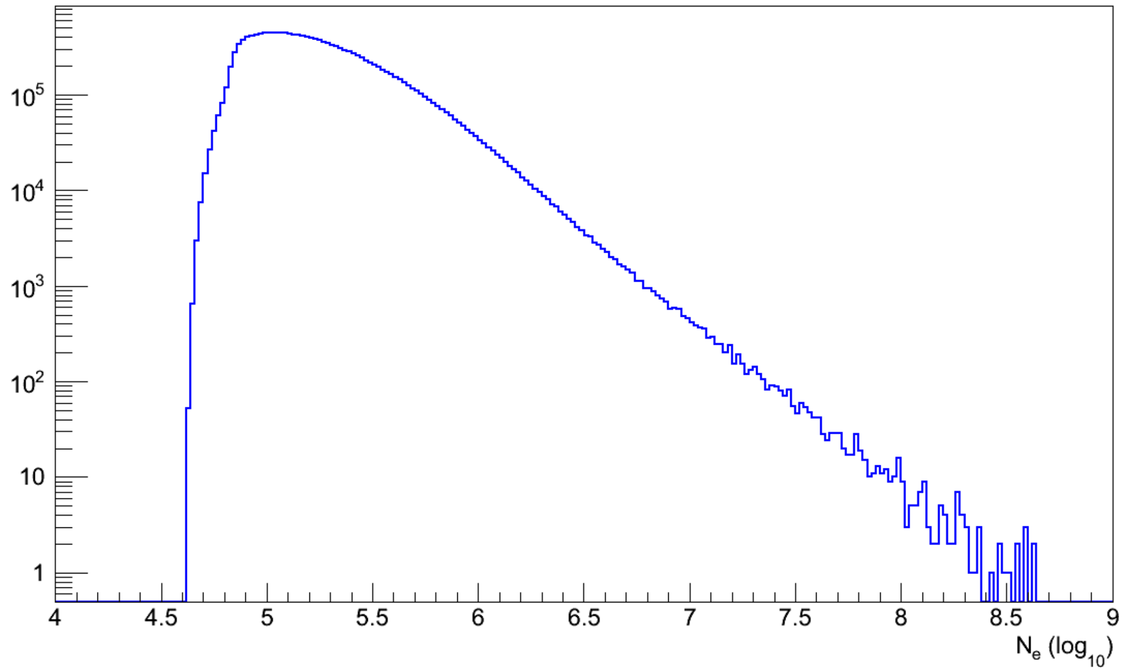


Fig. 3.2.1 *The spectrum of the reconstructed number of electrons*

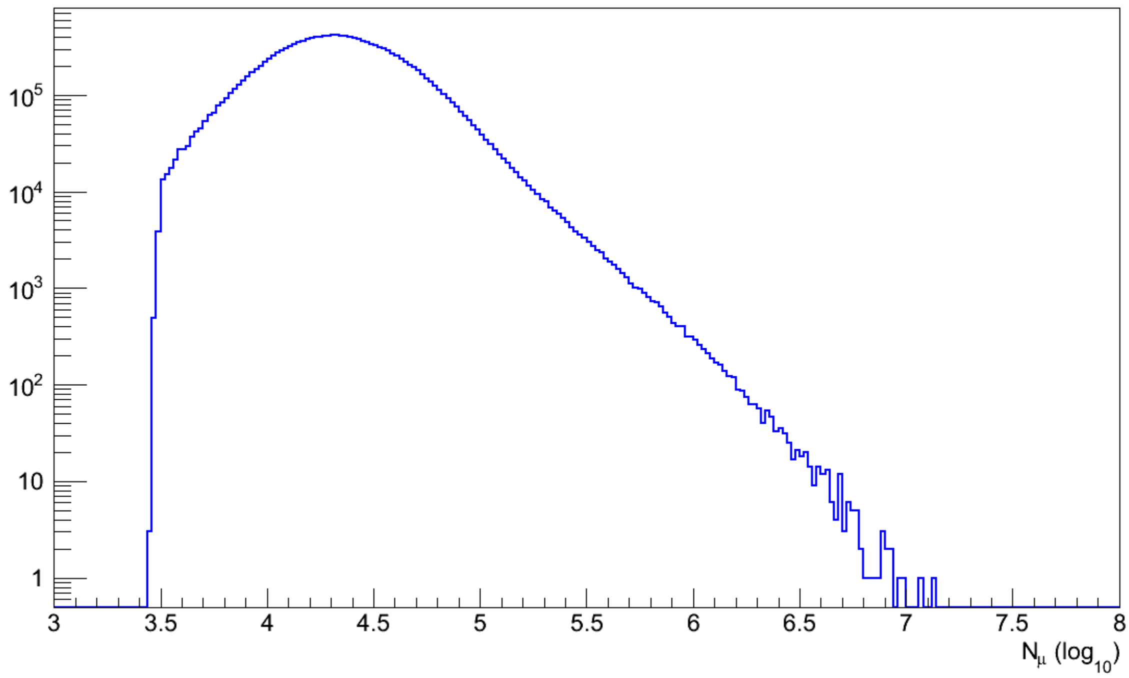


Fig. 3.2.2 *The spectrum of the reconstructed number of muons*

Fig. 3.2.3 shows the $lgN_{\mu} \; - lgN_{e}$ distribution as deduced from the Combined Data Analysis.

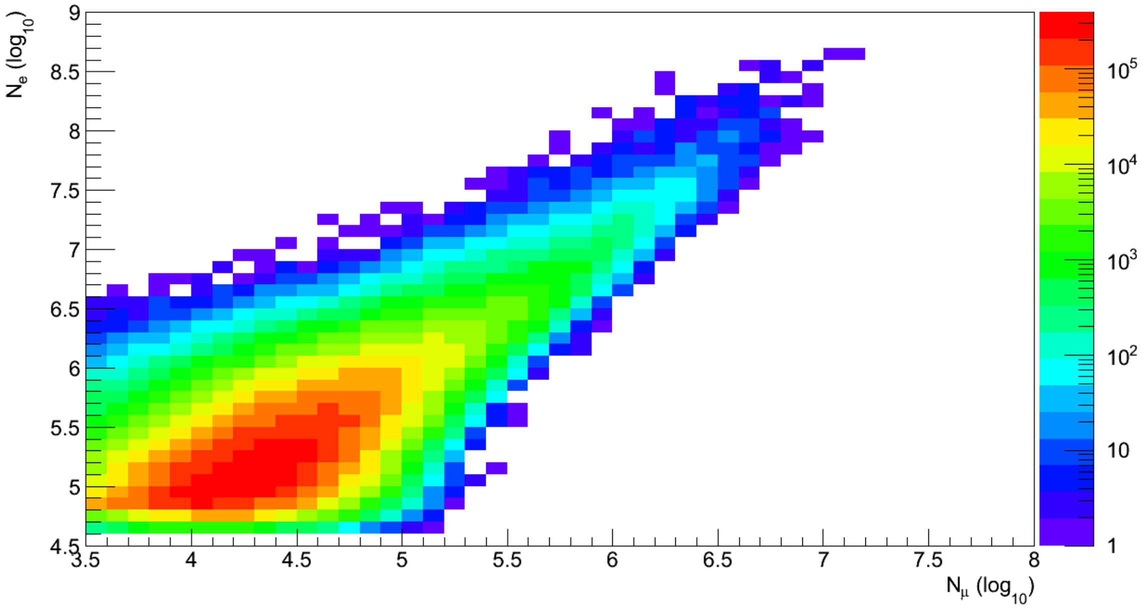


Fig. 3.2.3 $lgN_{\mu} - lgN_e$ *distribution measured fom COMBINED*

3.3 AGE (AGE)

Contrary to variables like number of electrons N_e or number of muons N_{μ}, the value of the Age parameter has no absolute meaning, as it depends on the choice of the lateral distribution function which is fitted to the shower data. It may also be called **lateral shape parameter** because it describes the steepness of the lateral electron density distribution. KASCADE uses a modified NKG-function to fit the lateral shower shape. Within this function, the age parameter values are limited theoretically to a range from 0.15 to 1.48.

The shape (steepness) of the lateral density distribution of a given shower depends on the energy of the primary particle, as well as on its nature. The higher the shower energy, the steeper the lateral distribution. A heavy primary particle with the same energy as a light one gives rise to a flatter lateral distribution, as the shower starts earlier in the atmosphere. When reaching ground, the shower is "older", which gives the Age parameter its name. The Age parameter therefore may help (in combination with number of electrons) to distinguish between primary particles of different mass.

Fig. 3.3.1 shows the distribution of the Age parameter within its valid range.

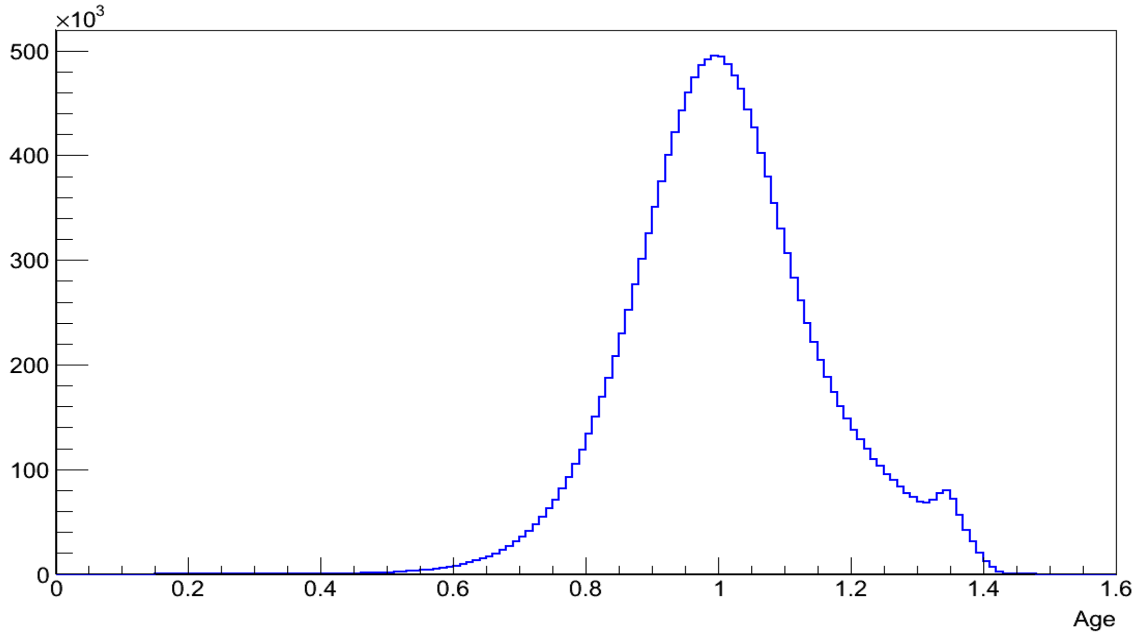


Fig. 3.3.1 *The AGE distribution from the modified NKG function for reconstructed showers.*

3.4 SHOWER CORE POSITION (XC, YC)

The Core Position is the reconstructed location of the shower centre at KASCADE-Grande level derived from the energy deposits of each detector station from KASCADE and GRANDE of one event. The unit of the core position is [m].

For the reconstruction of the core position in the COMBINED detector array basically the particle densities in every detector station are taken. By means of an *neural network algorithm* which combines high efficiency for the identification of the shower core with good rejection capability for showers that fall outside the fiducial volume, the core can be determined to a precission of about 1m. In addition, this method offers a simple approach to identify events with subcores.

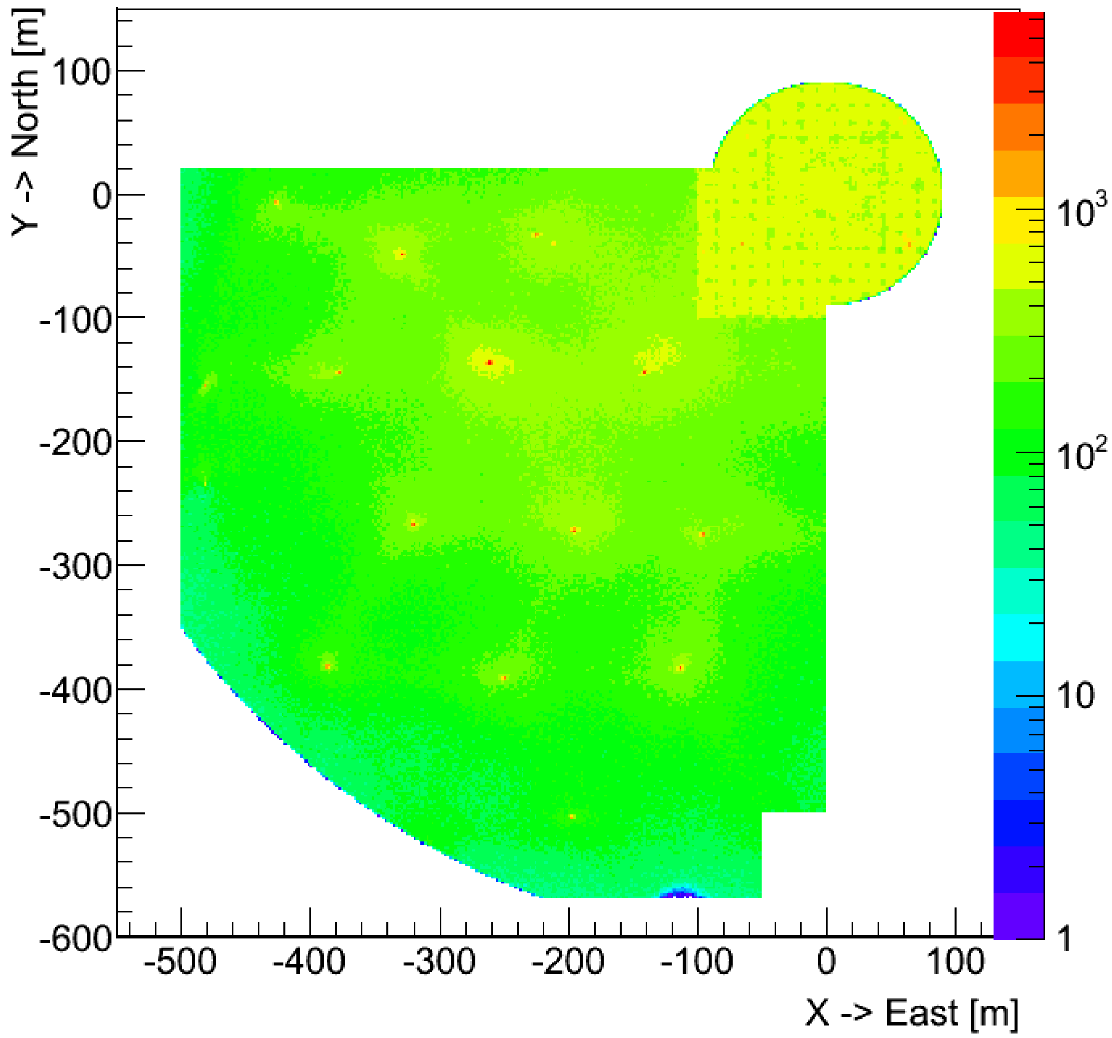


Fig. 3.4.1 *Shower core distribution from COMBINED analysis*

The distribution of the shower core is plotted in the fig. 3.4.1. Extensive air showers with a core position outside the detector area have a great probability for beeing incorrectly reconstructed. Therefore, only showers with a maximum core distance less than 91 m radius from the centre of the KASCADE detector and a well understood GRANDE detector area are taken into account.

The structure in the above picture is caused by an artefact in the reconstruction algorithm, which causes the centre of the shower core to be drawn between the stations with the highest measured energy deposits. For low energies the reconstruction algorithm draws the centre of the shower core towards the stations with the highest measured energy deposit. In the centre of the array the Central Calorimeter is located, thus four stations are missing.

3.5 SHOWER DIRECTION (ZE, AZ)

In KASCADE coordinates, the zenith angle is measured against the vertical direction, which means that θ=0° is pointing upwards and 90° denotes a horizontal shower. The azimuth is defined as an angle measured clockwise starting in northern direction (90° is east). The regular orientation of the KASCADE-Grande Array has an offset of about +15° against the real northern direction, caused by the fact that the conditions of the location (KIT, Campus North) allow only this orientation. This offset is corrected for in the data analysis. The unit of the azimuth and zenith angle is [°].

The KASCADE-Grande detectors measure the arrival times and the energy deposits of air shower particles, so that the shower directions are determined by evaluating the arrival times of the first particle in each detector station and the total particle number per station.

To calculate this shower centre the differences in the arrival times of the shower particles of the detector stations are used. After an individual time calibration of all stations where delay times and cable properties and electronics including the PMTs are taken into account, the differences of the times compared to the signal of the first station arriving at the central data acquisition are taken. To increase the accuracy, the energy deposits are taken into account when the direction of the shower disk is calculated.

In the first level of the reconstruction, the shower direction is estimated by a gradient method. This method is very fast and works without a minimisation procedure. It can deliver good starting values for the following reconstruction levels.

More detailed:

With a square root of the energy deposit $\sqrt{E}$, the weighted gradients $\frac{d_t}{d_x}$ and $\frac{d_t}{d_y}$ were filled in a two dimensional histogram. The gradient with the most entries from the channel was used to determine the shower direction. The angular resolution with these methods is 0.3 ° up to 1 ° depending on the shower energy. This is to account for the probability of an early particle at low densities.

In the second and third reconstruction levels, the shower direction is determined by the fitting of the function to the lateral distribution of the time signals. The form of the function has a significant effect on the size of the statistic and systematic errors of the estimated values. In the standard COMBINED reconstruction of KASCADE-Grande, the fitting of the arrival time is performed with a conical surface, i.e. the shower disk is not flat but a spherical segment.

In figure 3.5.1 the distributions of the azimuth angle is shown.

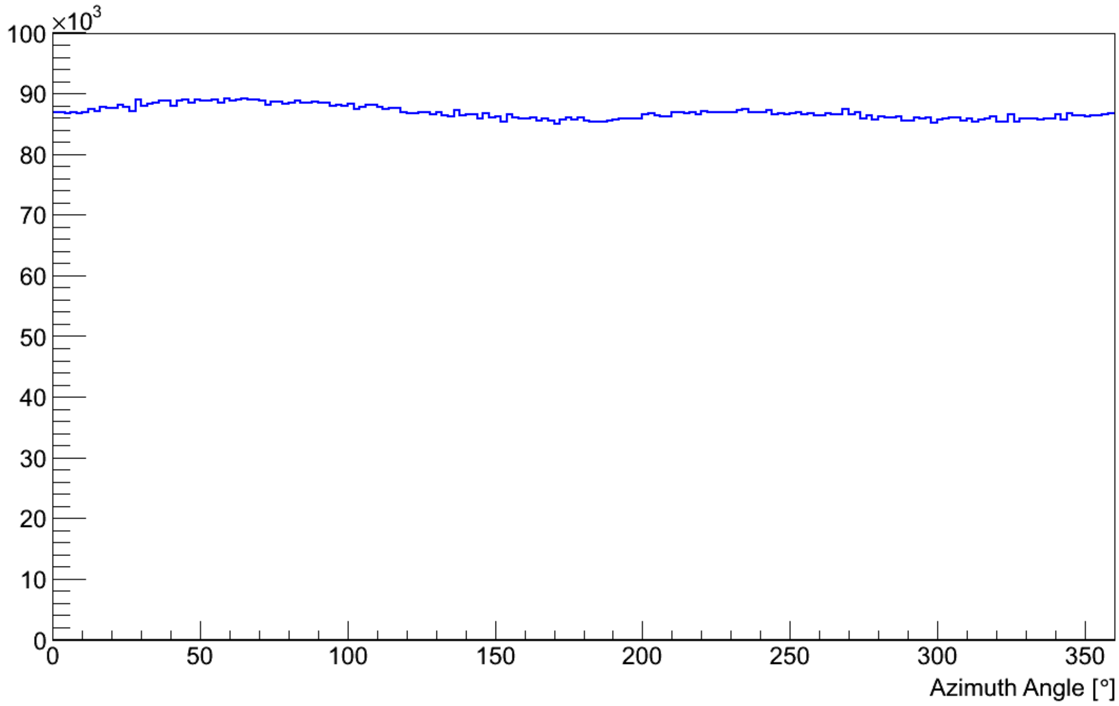


Fig. 3.5.1 *The distribution of the reconstructed azimuth angle*

The distribution of the zenith angle shown if fig 3.5.2. A cut has been applied at 30°.

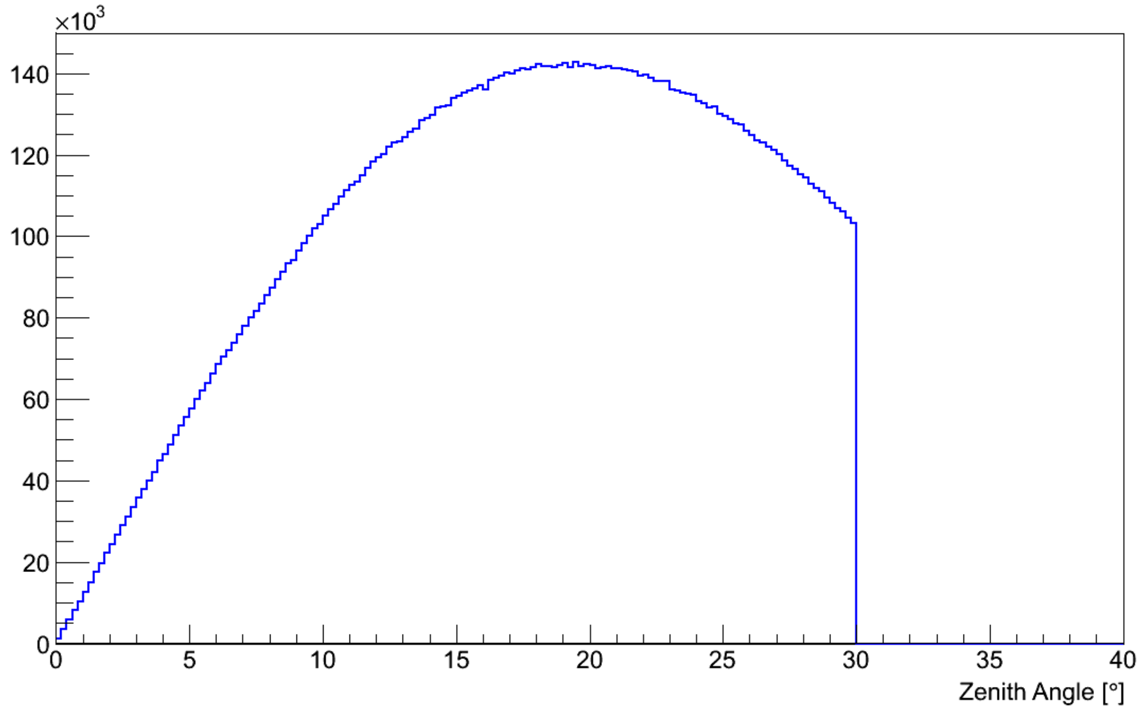


Fig. 3.5.2 *The distribution of the reconstructed zenith angle*

3.6 ENERGY ESIMATION (E)

One of the main goals of the air shower measurement is to determine the energy spectrum of the cosmic rays. Due to uncertainties in the hadronic interactions and the huge fluctuations in the shower size, this determination of energy and mass is rather challenging. In KASCADE, we measure the electromagnetic and muonic components of air showers separately, while in GRANDE only the charged component can be detected. By using all observables, we perform a transformation matrix in order to convert the number of electrons and muons to the energy of primary particles taking into account the angle of incidence. The parameters of the formula of the energy estimator are derived from extensive air shower simulations.

3.6.1 MEASURED DATA

From the measurements we derive the number of charged particles for each of the 252 detector stations and the 37 Grande stations separately. The number of muons is taken for each of the 192 outer Array detector stations. One can fit a function to the charged particles and muons separately. Due to saturation and punch through μ-detector stations within a radius of 40m around the reconstructed shower core are not taken into account.

In GRANDE, we can only measure the energy deposit of charged particles and photons together. There is no way to distinguish between electromagnetic particles and muons. Thus the measured data are the energy deposits of charged particles at ground level and their arrival times.

From these measurements, the arrival direction of the shower, its impact point on ground (shower core) and the total number of charged particles and muons in the shower, i.e. the shower sizes are reconstructed. The reconstruction is performed similar to KASCADE but with different parameters. The number of Muons (N_μ) are taken from the KASCADE detector stations participating in the respective event with a simplified method. As there are normally only few KASCDE detector stations with muon information when GRANDE has been triggered, the number of detected muons is compared to a shower with a normalised shower size. When the GRANDE core position is known, the average value of the ratio of '*measured muon number'*/'*expected muon number*' over all detectors are formed and stored as N_μ

The area underneath this so-called LDF (Lateral Density Function) is a measure for the number of charged particles and Muons. Subtracting the two curves and integrating leaves the number of Electrons (N_e). These two parameters are the basic input to the Energy Estimator.

3.6.2 SIMULATED DATA

For the air shower simulations the CORSIKA program (**CO**smic **R**ay **SI**mulation for **KA**SCADE) has been used by applying the hadronic interaction model of QGSjet-II-04 (Quark-Gluon-String Model, version II-4) for laboratory energies above 200 GeV. The low energy model Fluka 2012.2.14_32 has been used for energies below 200 GeV. All particles have been tracked down to the observation level at 110 m.a.s.l. The output of CORSIKA was fed into the detector simulation program CRES (**C**osmic **R**ay **E**vent **S**imulation) where the response of all detector components is taken into account by using the CERN GEANT3 package. The predicted observables at ground level, such as the number of electrons and muons are then compared to the measurements. Showers of five different mass groups indicated by five different primaries (*p*, *He*, *O*, *Si* and *Fe*) and photons have been simulated. The simulations cover the energy range of $1 \cdot 10^{14}$ to $3 \cdot 10^{18}$ eV with zenith angles in the interval 0° - 30°. The spectral index in the simulations was -2 to safe time and then corrected for the spectral index of the cosmic rays to -2.7.

In the COMBINED data analysis the simulations were also treated in the same way as the measured data.

For the parametrisation, the zenith angel range is from 0° to 17°. The selected data between $E = 10^{15} eV$ and $E = 3.2 \cdot 10^{18} GeV$ are divided in logarithmical equidistant energy intervals, where the mean values e/γ- and μ -distributions are determined.

3.6.3 Formula for Energy Estimator

For the energy estimation in the COMBINED analysis, we choose a very simple formula:

$$\lg(E) = 1.632 + 0.8907 * \lg(N_{e+} + N_{\mu})$$

The spectrum of the reconstructed energy of the primary particle for KASCADE Combined data analysis based on this formula is shown in Fig. 3.6.1. Clearly visible is that the full efficiency of the reconstruction is reached at about $10^{15.5}$ eV.

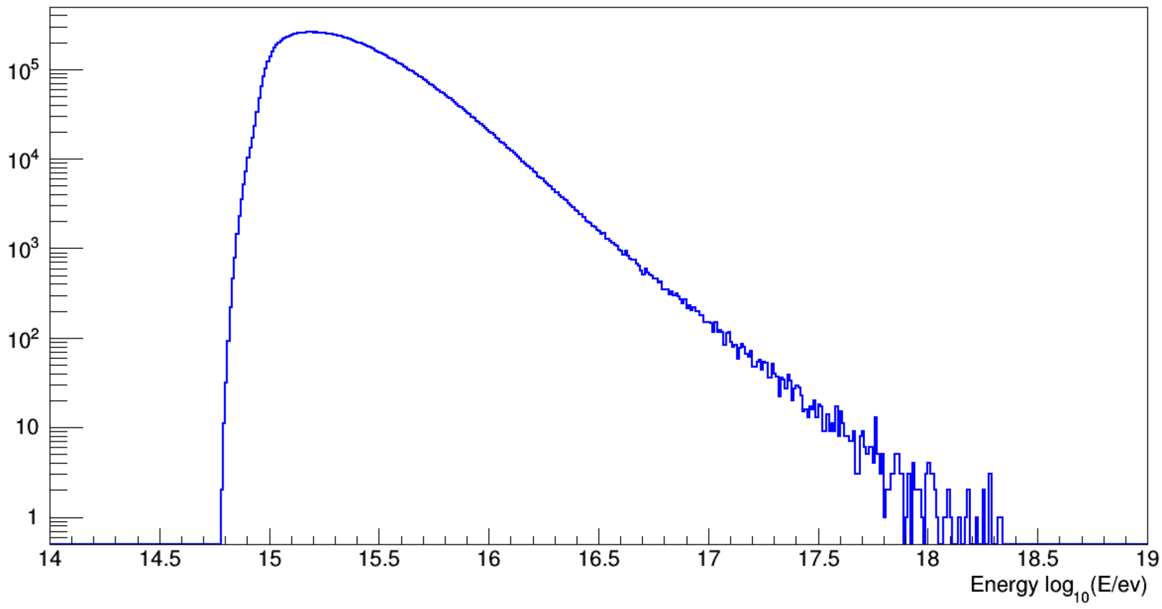


Fig. 3.6.1 *The reconstructed energy spectrum in log-log scale based on the simple energy estimator*

The table below illustrates the strong dependency of the number of remaining events from the cuts applied only on the Quantity ‚*Energy*' for all events reconstructed as combined events published in release PENTARUS.

Energy Cut	Nr of Events remaining
no cut	15,635,550
E > $5.0*10^{14}$	15,635,550
E > $1.0*10^{15}$	14,402,140
E > $5.0*10^{15}$	4,851,054
E > $1.0*10^{16}$	430,424
E > $5.0*10^{16}$	40,494
E > $1.0*10^{17}$	4,094
E > $5.0*10^{17}$	366
E > $1.0*10^{18}$	21

4 KASCADE ARRAYS DATA IN KCDC COMBINED

With the release of the COMBINED analysis, we publish the three data arrays from KASCADE, the energy deposits of electrons and muons and the arrival times per station as given by the reconstruction program KRETA.

KASCADE Quantity	Description	Unit	ID
Reconstructed Data			
e/γ - energy deposits	energy deposit in MeV / station [252]	*(MeV)*	*EDeposit*
μ - energy deposits	energy deposit in MeV / station [192]	*(MeV)*	*MDeposit*
Arrival Times	arrival Times / station [252]	*ns*	*Arrival*

In measurements, a detector station flagged 'inactive' or 'overflow' was excluded from the data analysis. Detector stations with no signal above the threshold are set to $E_{deposit}$=0 MeV.

The plots shown in this chapter are only examples, mostly based on a subsample of the data sets with primary energeis above 10^{15} eV. So, applying user cuts in your own analysis can change these spectra drastically.

4.1 ENERGY DEPOSITS PER STATION (EDEPOSIT, MDEPOSIT)

The publication of the energy deposits offers a new quality of KCDC to perform analysis with the KASCADE data. Available are the energy deposits of each single detector station independently measured in the e/γ- and in the μ-detectors.

A detector station has to fulfil several conditions to be treated as 'active detector station' in the sense that their energy deposits (EDeposit) and their muon energy deposit (MDeposit) values are provided.

- the station was flagged as 'active'
- no overflow was detected in the station

- the station was not deselected for various reasons

Active detector stations, which had no signal above the threshold, are as well taken into account. No energy value of these 'silent' stations is given, just the station ID (EDepositS) is stored.

Note: on the quantities 'Energy Deposit' no cuts can be applied

Note: in chapter 8.4 are examples on how to handle the quantity 'Energy Deposit'

4.1.1 E/γ – Energy Deposits

Handling the **'e/γ Energy Deposits'** quantity mostly requires some additional information either on the absolute coordinates of the detector station or on the distance to the reconstructed shower core. Therefore, the quantity **EDepositS** is always supplied with the energy values. Furthermore, the number of detector stations with valid energy deposit information (**EDepositN**) is provided as well.

Thus, if the quantity '**e/γ Energy Deposit'** is selected in the KCDC DataShop you will always be supplied with the following data sets:

EDepositN	number of active e/γ-detector stations with energy deposit ≥ 0
EDeposit	energy deposit per station in MeV
EDepositS	detector station ID [1…252]

4.1.1.1 Number of active e/γ-detector stations (EDepositN)

The range of active e/γ-detector stations stored in **EDepositN** is between 1 and 252. The distribution for **EDepositN** is shown in Fig. 4.1.1. The lower limit is given by the selection condition that at most two array clusters (32 stations) may be missing in the respective event. As there may be more single stations flagged as '*inactive',* the number can be below 220. On the other hand, if the shower cores lies within Grande, far away from the KASCADE array only a few stations can be involved in the event (see also fig. 4.1.2). The peak structure is caused by the cluster geometry of the KASCADE array (see "KCDC User Manual" chapter 2.2) i.e. the probability that a whole cluster is missing.

Note: only active stations are used for further analysis and shown in the plot.

Note: This value is always shipped if the 'e/γ Energy Deposit' Quantity is selected but only in root and hdf5 files not in ASCII.

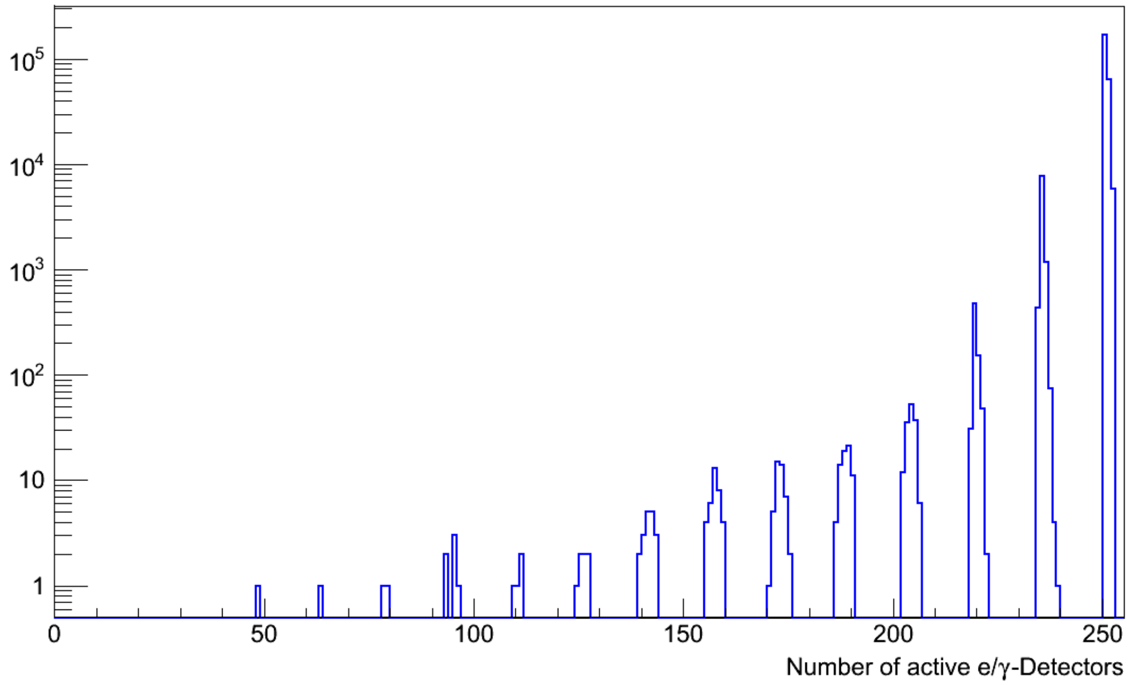


fig. 4.1.1 *Distribution of the number of active e/γ –detector stations*

4.1.1.2 Number of e/γ-detector stations with hits

The distribution of the number of **e/γ-**detectors with *EDeposit>0* in this event is given in fig 4.1.2.

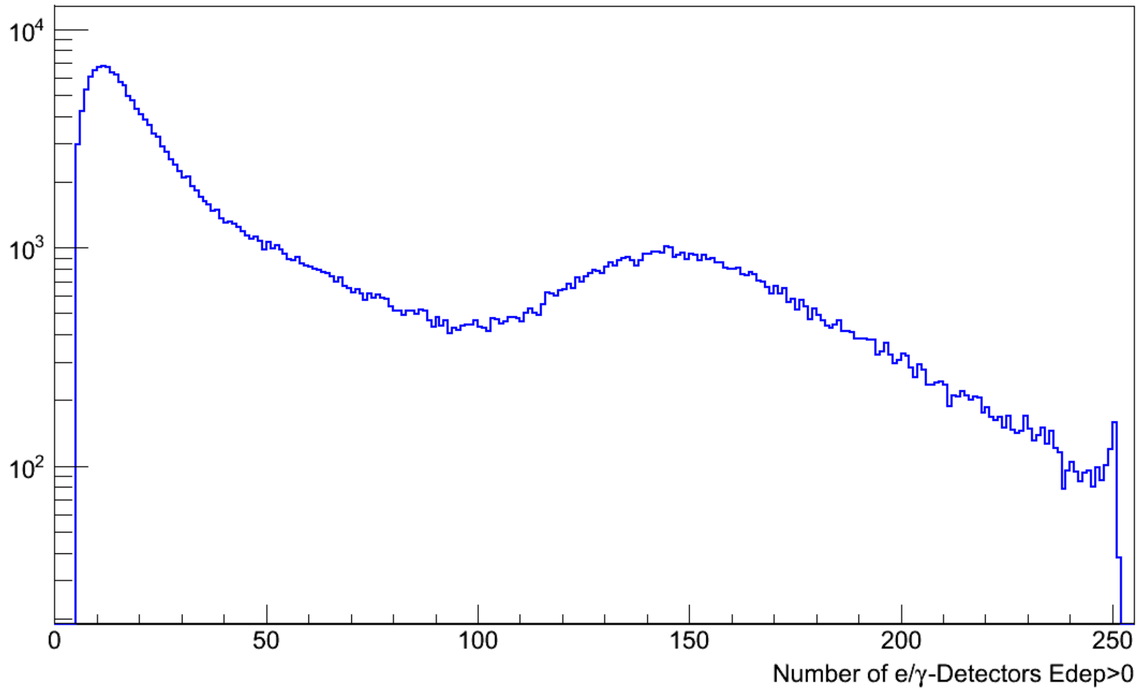


fig. 4.1.2 *Distribution of the number of e/γ –detector stations with hits*

4.1.1.3 e/γ Energy Deposit for each detector station (EDeposit)

The Energy deposits are derived from the stored ADC values for each detector station by means of a calibration procedure where the influences of electronics and cabling are included. EDeposit values are given in MeV. In fig 4.1.3, the energy deposits for a subsample of data are plotted.

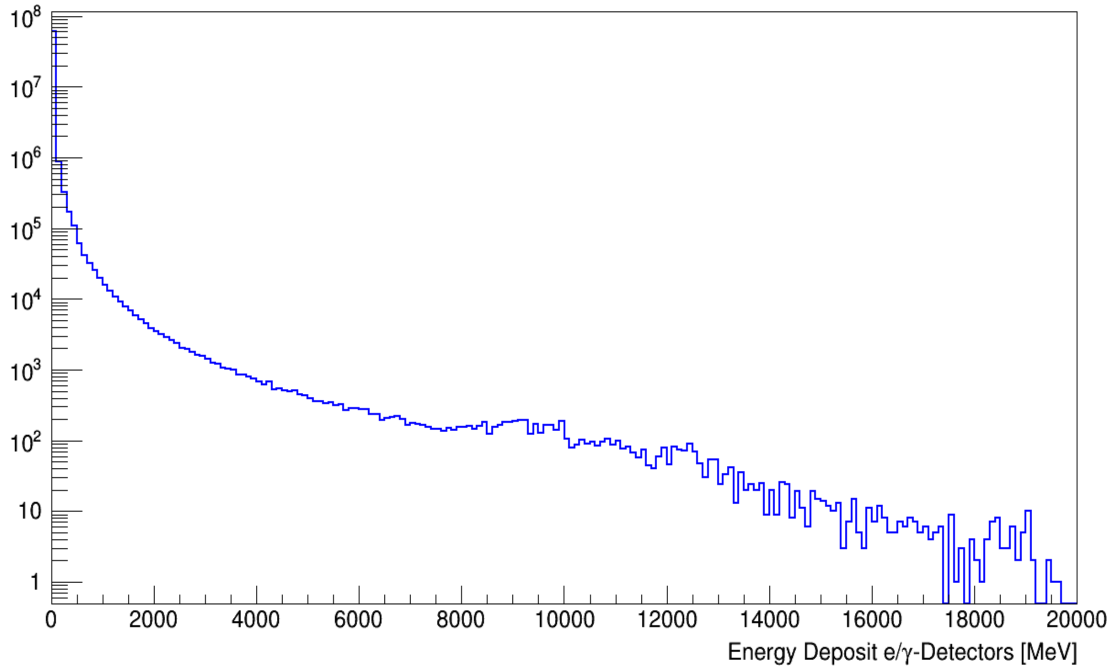


fig. 4.1.3 *Distribution of the calibrated e/γ –Energy Deposits of all active stations*

4.1.1.4 Station ID (EDepositS)

The station ID holds the information of the location of the respective detector station. The transformation from the station ID to the true detector position in KASCADE coordinates of the respective Array detector station is in detail described in chapter 8.4 and Appendix A.

Fig 4.1.4 shows the distribution of station IDs of the active e/γ-detector stations. The steps in the otherwise very flat spectrum indicate that one station or a whole cluster (16 stations) were missing for some time.

Note: This value is always shipped if the ‘e/γ Energy Deposit’ Quantity is selected but only in root and hdf5 files not in ASCII.

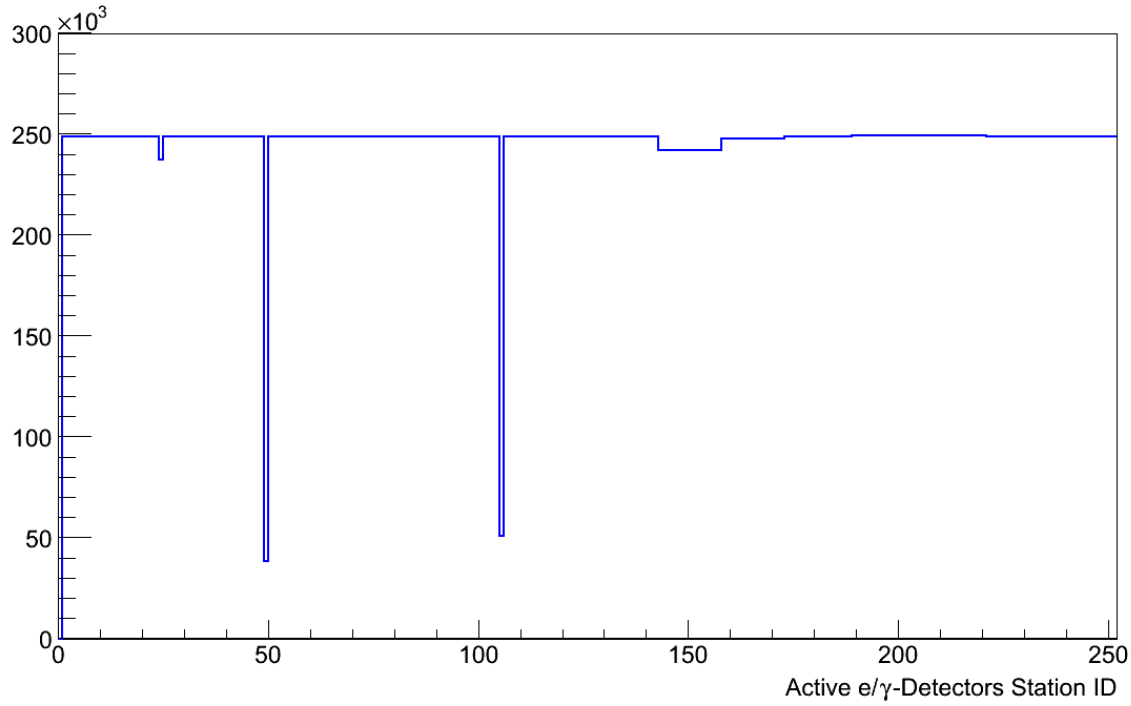


Fig. 4.1.4 ***Distribution of station IDs for active e/γ-detector stations***

For further studies the effective e/γ –detector area for a given station can be derived from the station ID. As described in the "KCDC User Manual" chapter 2.2 two different detector setups are realised in the KASCADE array. The inner 4 clusters consist of only 15 stations each, (the 16th position is blocked by the Central Calorimeter) and are equipped with 4 liquid scintillator cones with an effective area of 3.14m² to measure the shower core. The outer 12 cluster have two liquid scintillation e/γ-detectors with an effective area of 1.57m² (see fig. 4.1.5). The table below shows the correlation between station ID and effective detector area.

Station ID	**Area [m²]**	**Area Code**
1 - 80	1.57	0
81 – 110	3.14	1
111 – 142	1.57	0
143 – 172	3.14	1
173 – 252	1.57	0

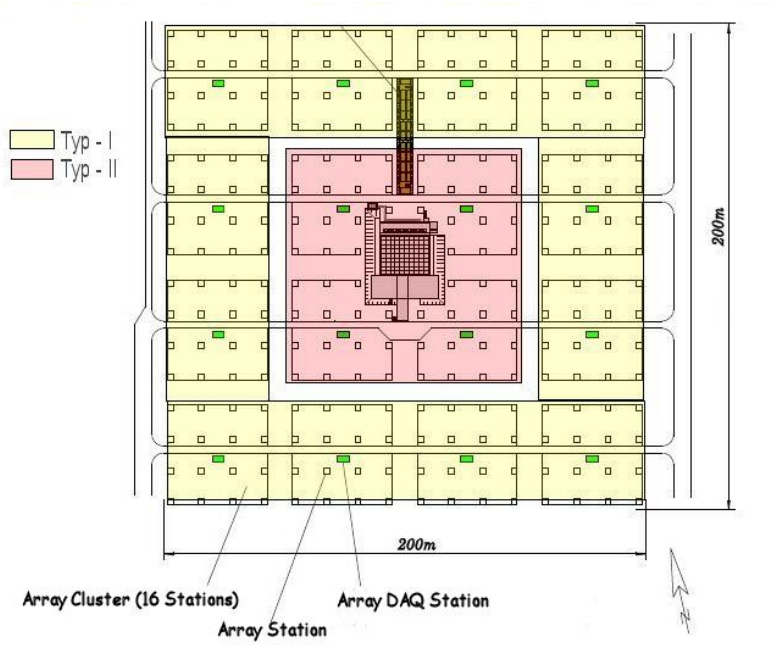


Fig. 4.1.5 *Array setup, schematic view of the KASCADE detector array*
yellow: two e/γ-detectors ,1.57m² plus the muon detectors per station;
red: four e/γ-detectors, 3.14m² per station no muon detectors;

4.1.2 MUON – ENERGY DEPOSITS

Handling the '**Muon Energy Deposits'** quantity mostly requires some additional information either on the absolute coordinates of the detector station or on the distance to the reconstructed shower core. Therefore, the quantity **MDepositS** is always supplied with the Energy Deposit values. Furthermore, the number of detector stations with valid energy information (**MDepositN**) is provided as well.

Thus, if the quantity **'Muon Energy Deposit' ('MDeposit')** is selected in the KCDC DataShop you will always be supplied the following data sets:

MDepositN	number of active μ-detector stations with energy deposit ≥ 0
MDeposit	muon energy deposit per station in MeV
MDepositS	detector station ID

4.1.2.1 Number of active µ-detector stations (MDepositN)

The range of **MDepositN** is between ca. 1 and 192. The distribution for **MDepositN** is given in Fig. 4.1.6. The lower limit is given by the selection condition that at most two array clusters (32 stations) may be missing in the respective event. As there may be single stations flagged as '*inactive'* the number can be below 160. Furthermore, µ-detectors within a radius of 40m around the reconstructed shower core are not used because of the saturation and the punch through which cannot be estimated accurately and thus not corrected for. On the other hand, if the shower cores lies within Grande, far away from the KASCADE array only a few stations can be involved in the event (see also fig. 4.1.7).

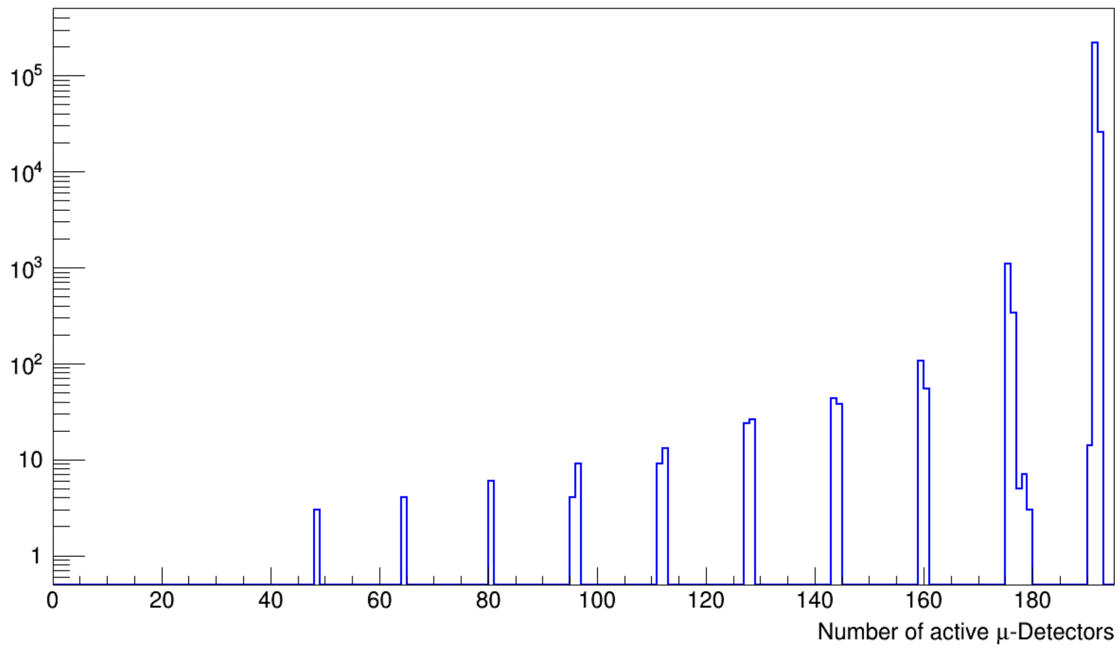


fig. 4.1.6 Distribution of the number of active µ–detector stations

Note: This value is always shipped if the 'Muon Energy Deposit' Quantity is selected but only in root and hdf5 files not in ASCII.

4.1.2.2 Number of µ-detector stations with hits

The distribution of the number of µ-detectors with energy deposit *MDeposit>0* in this event is given in fig 4.1.7.

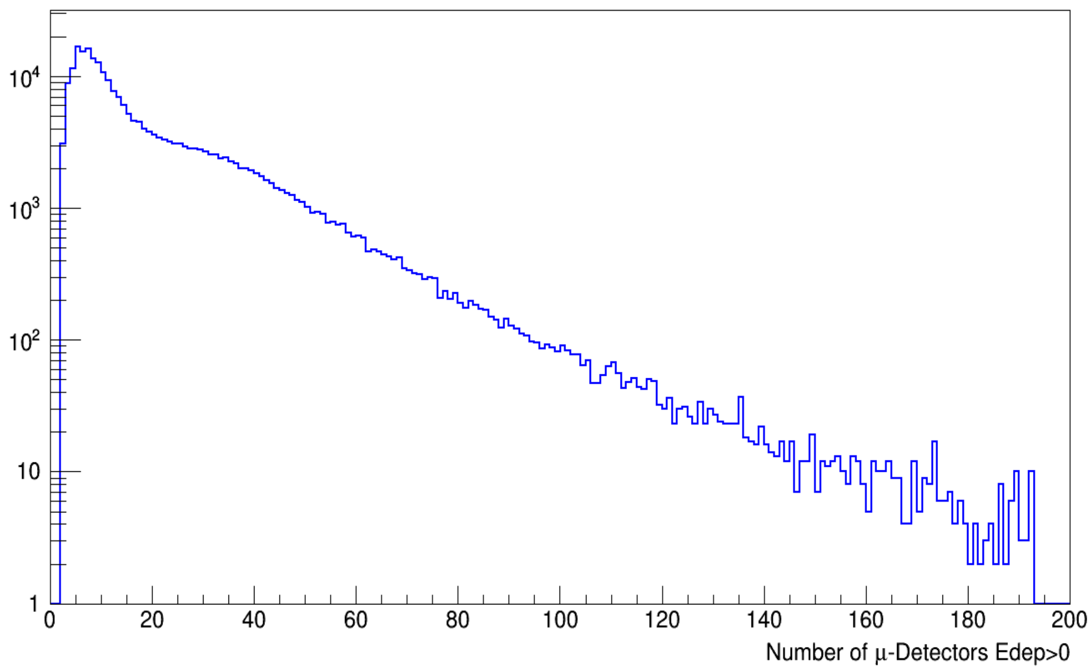


fig. 4.1.7 *Distribution of the number of μ–detector stations with hits*

4.1.2.3 μ-Energy Deposit value for each detector station (MDeposit)

The Energy deposits are derived from the stored ADC values for each μ detector station by means of a calibration procedure where the influences of electronics and cabling are included. **MDeposit** values are given in MeV. In fig 4.1.8 the energy deposits for a subsample of KASCADE data are plotted.

Note: Muon energy deposits within a 40m radius around the reconstructed shower core are not in the data samples because of the saturation and the punch through effects, which cannot be estimated and thus not corrected for.

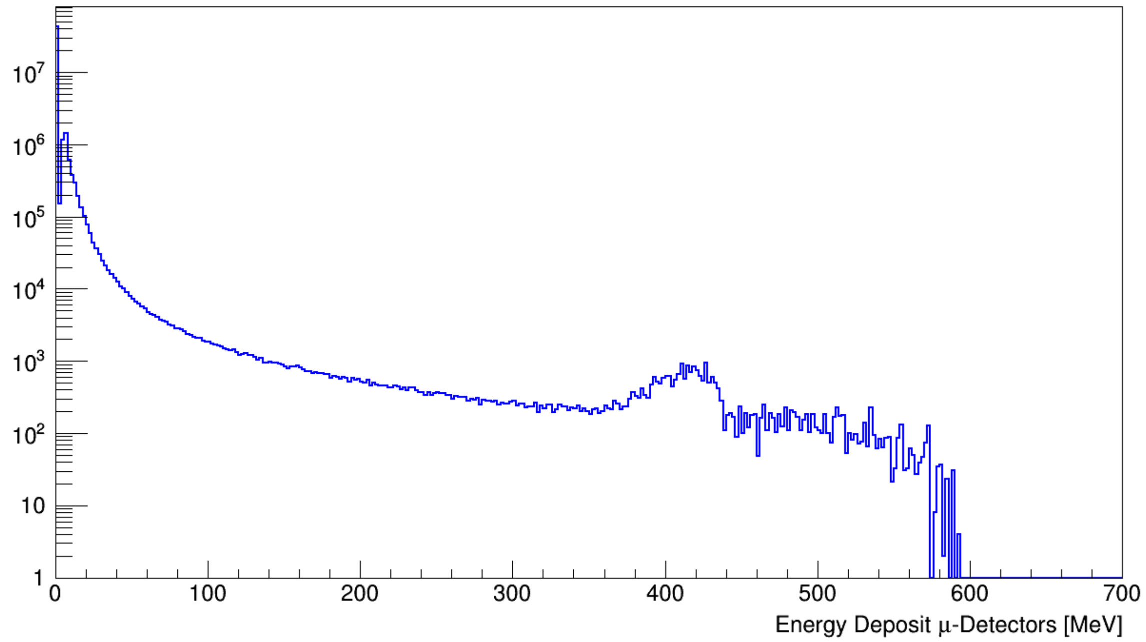


fig. 4.1.8 *Distribution of the corrected μ energy deposits of all active stations*

4.1.2.4 Station ID (MDepositS)

The *station ID (same as for e/γ-detectors in 4.1.1.4)* holds the information of the location of the respective detector station. The transformation from the *station ID* to the KASCADE coordinates of the respective Array detector station is in detail described in chapter 8.4 and Appendix A.

Fig 4.1.9 shows the distribution of station IDs of the active μ-detector stations. The two regions not populated represent the 4 inner array clusters, which are not equipped with μ-detectors (see "KCDC User Manual" chapter 2.2). The other steps in the otherwise very flat spectrum indicate that one station or a whole cluster (16 stations) were missing for some time.

The effective μ–detector area for all 192 stations is 3.24 m² (yellow area in fig 4.1.5).

Note: This value is always shipped if the 'μ Energy Deposit' Quantity is selected but only in root and hdf5 files not in ASCII.

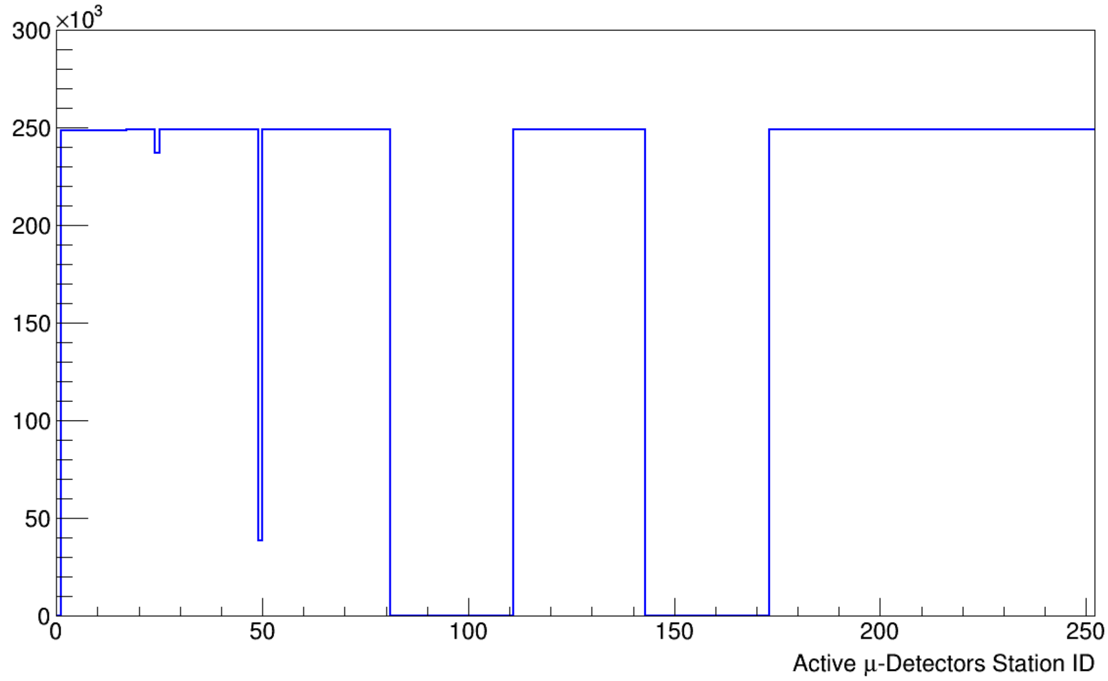


Fig. 4.1.9 *Distribution of station IDs for μ-detector stations*

4.2 ARRIVAL TIMES

The '**Arrival Times'** of each KASCADE and GRANDE array station represents the first time stamp of each detector station that has been hit by a charged particle. When the electronic has recorded a signal above a certain threshold a signal is sent to the central data acquisition system. The first signals of each station represent the shower front and are used to determine the shower direction.

The quantity '**Arrival Time'** offers the possibility to reconstruct the shower disc and the arrival direction of the extensive air shower.

The values of the arrival times are taken from the e/γ –detector's data.

A detector station has to fulfil several conditions to be accepted as 'active detector station' for arrival time analysis.

- the station was flagged as 'active'
- no overflow was detected in the station
- the station was not deselected for various reasons

A detector station, which did not provide any time information, was treated as 'silent station'.

Note: on the quantity 'Arrival Times' no cuts can be applied

Note: in chapter 8.4 are examples on how to handle the quantity 'Arrival Times'

Handling the '**Arrival Times'** quantity mostly requires some additional information either on the absolute coordinates of the detector station or on the distance to the reconstructed shower core. Therefore the quantity **ArrivalS** is always supplied with the times values. Furthermore, the number of detector stations with valid arrival time information (**ArrivalN**) is provided as well.

Thus, if the quantity '**Arrival Times'** is selected in the KCDC DataShop you will always be supplied with the following data sets:

ArrivalN	nr of active e/γ-detectors for this event (0 … 252)
Arrival	Arrival time in [ns] bins
ArrivalS	detector station ID [1…252]

4.2.1.1 Number of detector stations with valid arrival times (ArrivalN)

The range of **ArrivalN** is between about 15 and 252. The distribution is shown in fig. 4.2.1. The lower limit is given by the trigger condition described in chapter 3.1.2. of the "KCDC User Manual".

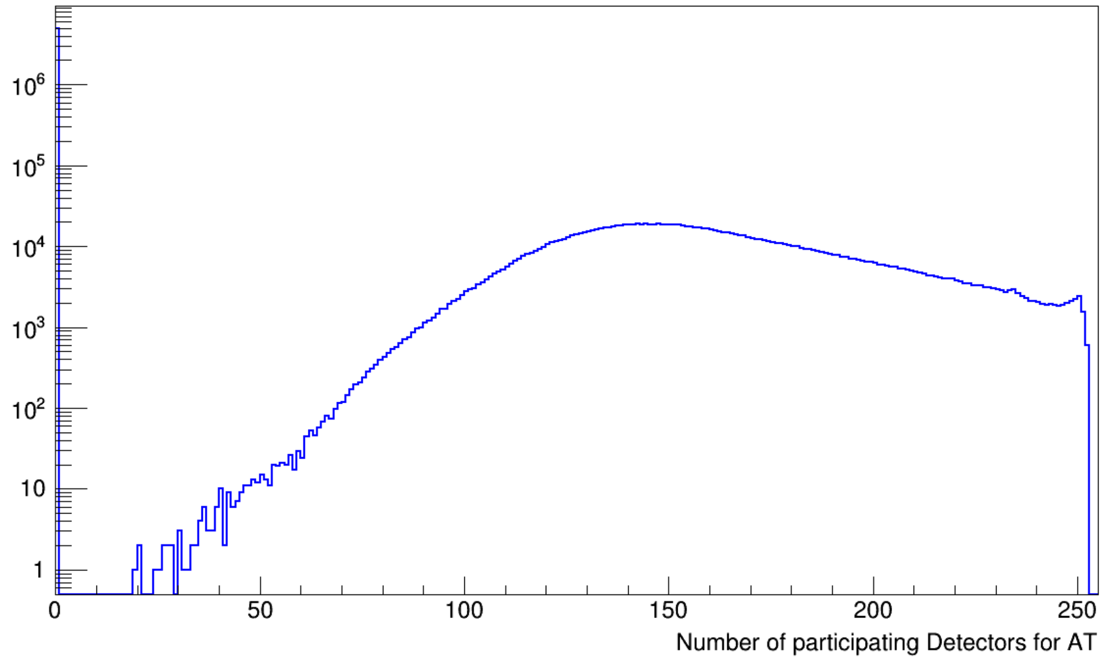


fig. 4.2.1. ***Distribution of the number of detector stations with 'Arrival' information***

4.2.1.2 Arrival Times per Station (Arrival)

The arrival times are given with a resolution of 1ns/bin. Fig 4.2.2 shows the 'arrival'– distribution. The values of the arrival times can be negative due to the fact that the reference to calculate the individual time stamps is not the first signal above a certain threshold but the time of coincidence that matches the trigger condition set in the hardware. Going to higher Energies the negative Arrival Time values will disappear as indicated in the red curve of fig. 4.2.2 where a cut as been applied on N_e > 500,000.

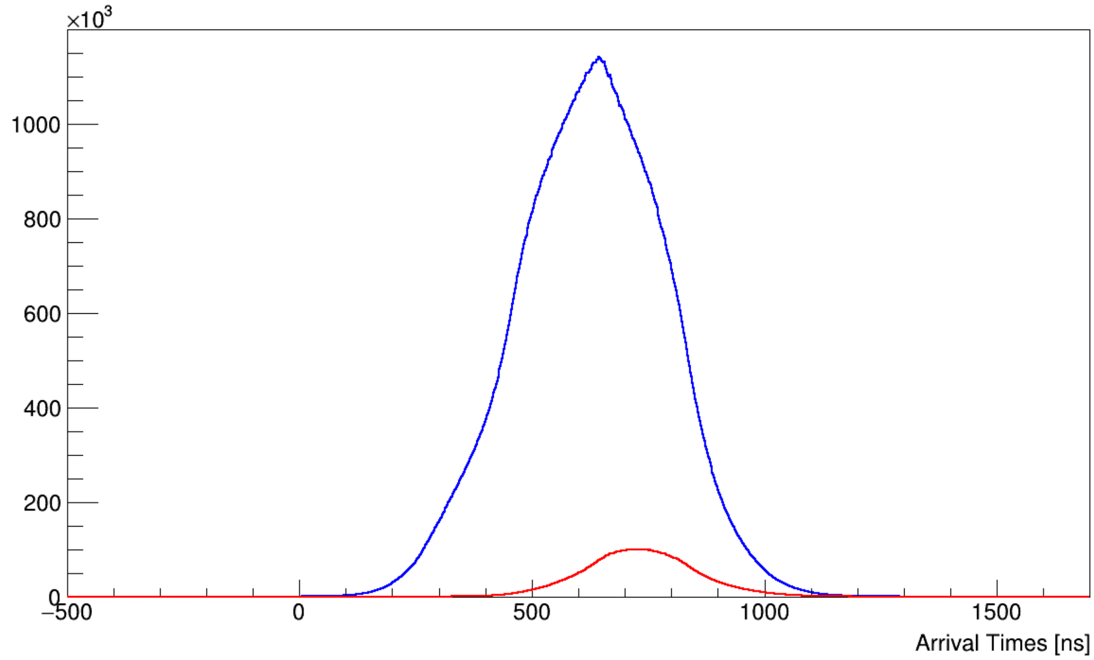


fig. 4.2.2 ***Arrival time distribution; no N_e cuts(blue); N_e>500000 (red)***

4.2.1.3 Station ID (ArrivalS)

The station ID (same as in 4.1.1.4) holds the information of the location of the respective detector station. The transformation from the *station ID* to the KASCADE coordinates of the respective Array detector station is in detail described in chapter 8.4 and App-A.

Fig 4.2.3 shows the distribution of station IDs of the active e/γ-detector stations. The two regions with the higher population mark the four inner clusters which have a detection area twice the size of the outer 12 clusters (see fig. 4.1.5).

Note: This value is always shipped if the 'Arrival' Quantity is selected but only in root and hdf5 files not in ASCII.

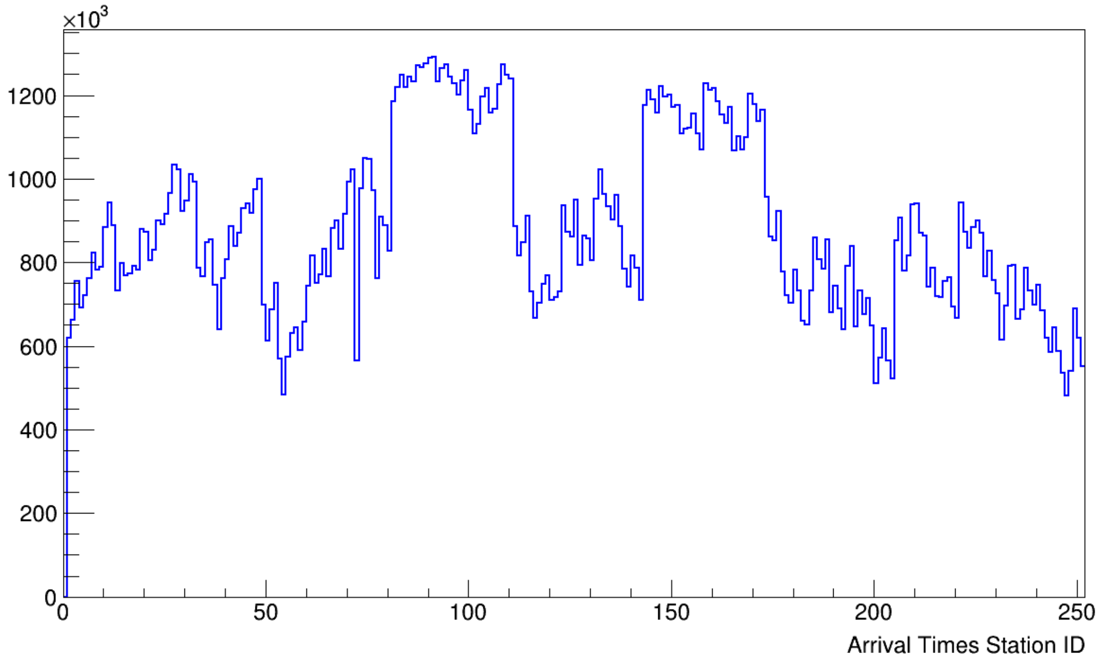


fig. 4.2.3 ***Distribution of station IDs for e/γ-detector stations with valid Arrival Times***

4.2.1.4 EXAMPLE

An example for the arrival time distribution of one event is given in fig 4.2.5. The warmer the colour the bigger the time difference which usually corresponds to larger zenith angles. The arrival time distribution and the large difference in the arrival time of about 600ns indicate that the shower is coming from south-west direction at a zenith angle of about 30°.

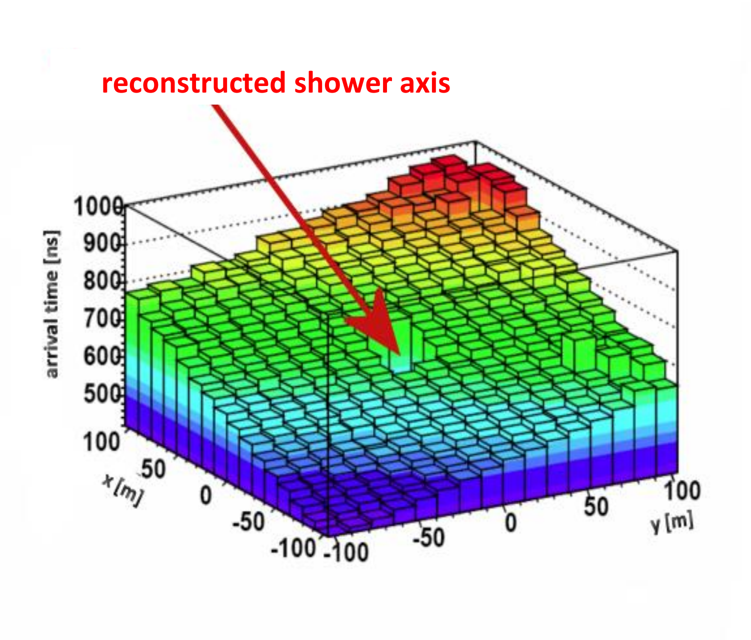


Fig. 4.2.5 *Example of an arrival time distribution with the reconstructed shower direction*

5 GRANDE ARRAYS DATA IN KCDC COMBINED

With the release of the COMBINED analysis, we publish the two data arrays from GRANDE, the energy deposits of the charged particles and the arrival times per station as given by the reconstruction program KRETA (Kascade Reconstruction for ExTensive Airshowers).

GRANDE Quantity	Description	Unit	ID
Measured Data			
Energy Deposits	charged energy deposit per GRANDE detector station	*(MeV)*	*GDeposit*
Arrival Times	Arrival Times per GRANDE detector station	*(ns)*	*GArrival*

The plots shown in this chapter are only examples, mostly based on a subsample of the data set published. So, applying user cuts either in the KCDC Data Shop or in your own analysis can change these spectra drastically.

5.1 GRANDE ENERGY DEPOSITS PER STATION (GDEPOSIT)

Available are the GRANDE energy deposits of each of the 37 detector stations.

A detector station has to fulfil several conditions to be treated as 'active detector station' in the sense that their energy deposits and arrival times are provided.

- the station was flagged as 'active'
- no overflow was detected in the station
- the station was not deselected for various reasons

Active detector stations, which had no signal above the threshold, are as well taken into account. The energy value of these 'silent' stations is set to '0'.

Note: on the quantities 'GRANDE Energy Deposit' no cuts can be applied

Note: in chapter 8.5 are examples on how to handle the quantity 'GRANDE Energy Deposit'

Handling the **'GRANDE Energy Deposits'** quantity mostly requires some additional information either on the absolute coordinates of the detector station or on the distance to the reconstructed shower core. Therefore, the quantity **GDepositS** is always supplied with the energy values. Furthermore, the number of detector stations with valid energy deposit information (**GDepositN**) is provided as well.

Thus, if the quantity '**GDeposit'** is selected in the KCDC DataShop you will always be supplied with the following data sets:

GDepositN	number of active GRANDE detector stations with energy deposit ≥ 0
GDeposit	energy deposit per station in MeV
GDepositS	detector station ID [1…37]

5.1.1 Number of active GRANDE detector stations (GDepositN)

The range of **GDepositN** is in this analysis roughly between 30 and 37. The distribution for **GDepositN** is given in Fig. 5.1.1.

Note: only active stations are used for further analysis and shown in the plot.

Note: This value is always shipped if the 'GRANDE Energy Deposit' Quantity is selected but only in root and hdf5 files not in ASCII.

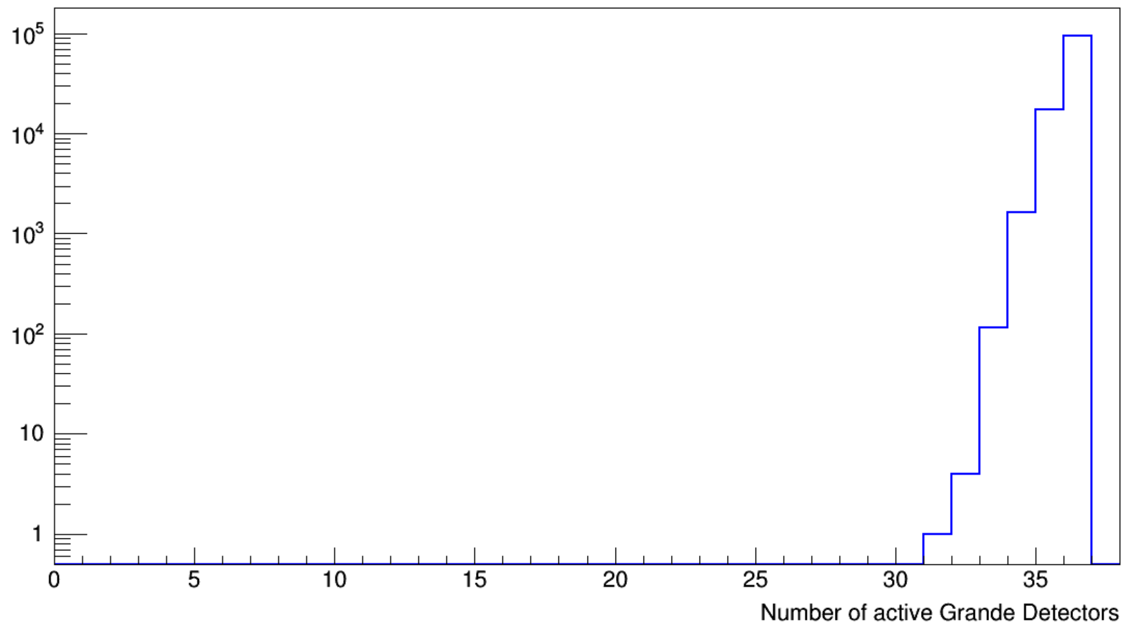


fig. 5.1.1 ***Distribution of the number of active GRANDE detector stations***

5.1.2 GRANDE Energy Deposit for each detector station (GDeposit)

The Energy deposits are derived from the ADC values for each GRANDE station by means of a calibration procedure where the influences of electronics and cabling are taken into account. **GDeposit** values are given in MeV. In fig 5.1.2 the energy deposits for a subsample of GRANDE data is plotted.

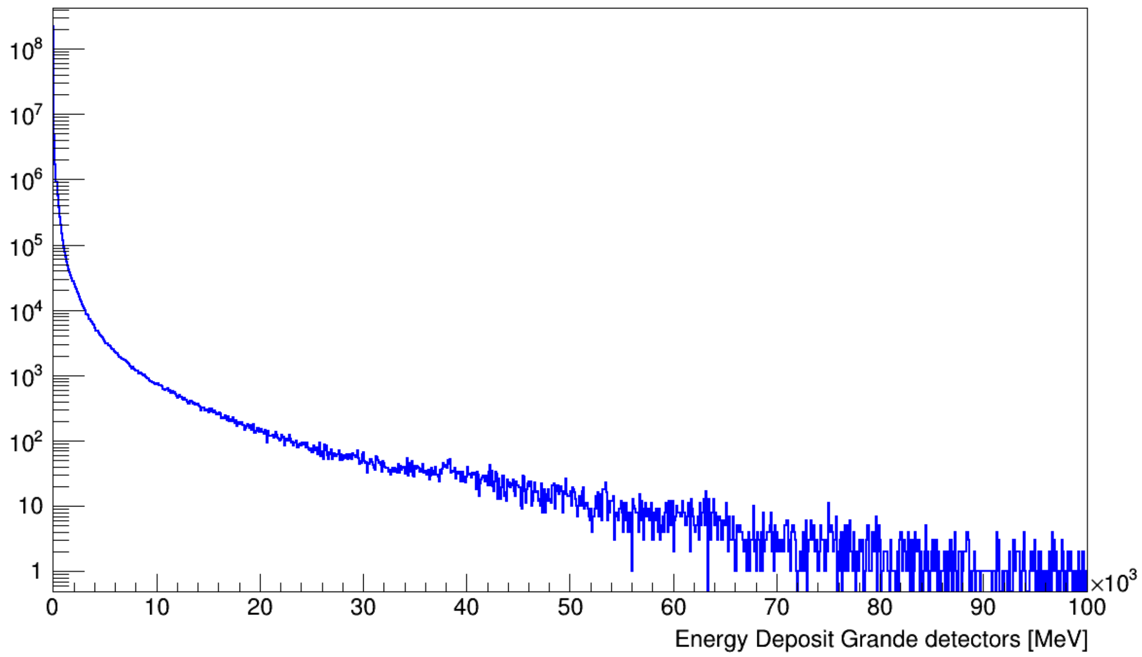


fig. 5.1.2 *Distribution of the GRANDE Energy Deposits of all active stations*

5.1.3 Station ID (GDepositS)

The station ID holds the information of the location of the respective detector station. The transformation from the station ID to the true detector position in KASCADE coordinates of the respective GRANDE detector station is in detail described in chapter 8.5 and Appendix B.

Fig 5.1.3 shows the distribution of station IDs of the active GRANDE detector stations. The step in the otherwise very flat spectrum indicates that a single station was missing for some time.

Note: This value is always shipped if the 'GRANDE Energy Deposit' Quantity is selected but only in root and hdf5 files not in ASCII.

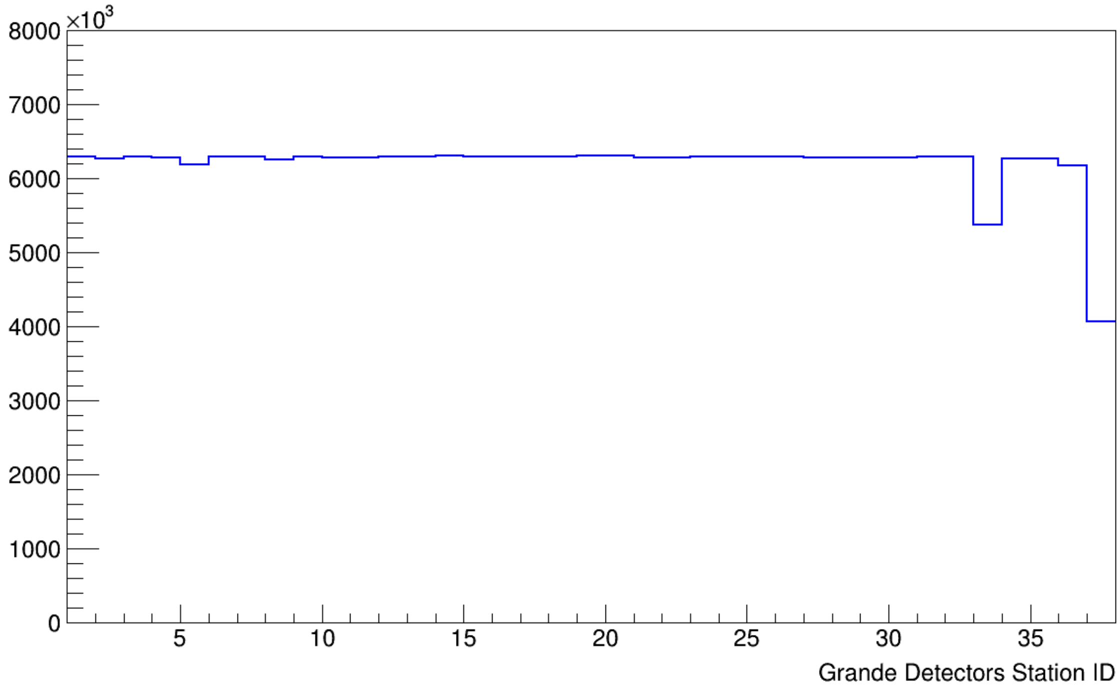


Fig. 5.1.3 *Distribution of active GRANDE detector stations*

5.2 ARRIVAL TIMES

The '**GRANDE Arrival Times'** of each GRANDE array station represents the first time stamp of each detector station that has been hit by a charged particle. When the electronic has recorded a signal above a certain threshold a signal is sent to the central data acquisition system, the GRANDE DAQ. The first signals of each station represent the shower front and are used to determine the shower direction.

The quantity '**GRANDE Arrival Time'** offers the possibility to reconstruct the shower disc and the arrival direction of the extensive air shower within the COMBINED data analysis.

A detector station has to fulfil several conditions to be accepted as 'active detector station' for GRANDE arrival time analysis.

- the station was flagged as 'active'
- no overflow was detected in the station
- the station was not deselected for various reasons

A detector station, which did not provide any time information, was treated as 'silent station'.

Note: on the quantity 'GArrival' no cuts can be applied

Note: in chapter 8.5 are examples on how to handle the quantity 'GRANDE Arrival Times'

Handling the '**GArrival'** quantity mostly requires some additional information either on the absolute coordinates of the detector station or on the distance to the reconstructed shower core. Therefore the quantity **GArrivalS** is always supplied with the times values. Furthermore, the number of detector stations with valid arrival time information (**GArrivalN**) is provided as well.

Thus, if the quantity '**GRANDE Arrival Times'** is selected in the KCDC DataShop you will always be supplied with the following data sets:

GArrivalN	number of active GRANDE detector stations for this event [0 … 37]
GArrival	Arrival time in [ns] bins
GArrivalS	detector station ID [1…37]

5.2.1 Number of GRANDE detector stations with valid arrival times (GArrivalN)

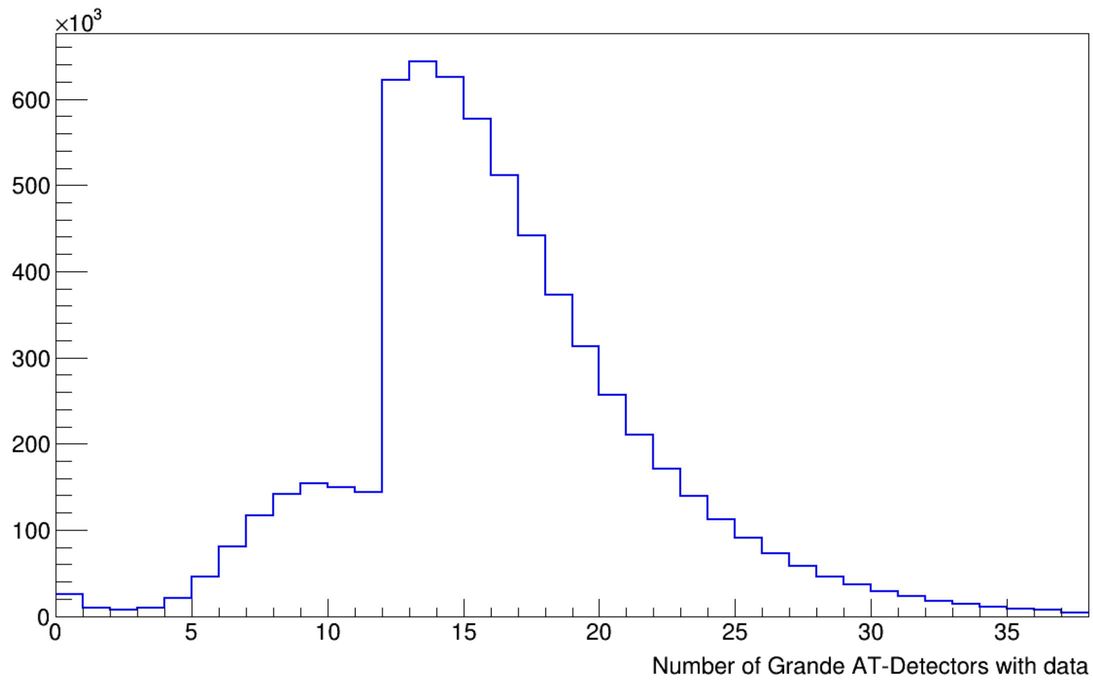


fig. 5.2.1. *Distribution of the number of active detector stations for 'Arrival Times'*

The range of **GArrivalN** is shown in fig. 5.2.1. The showers below N=12 are reconstructed with KASCADE parameters in the Combined analysis. If the shower core is within GRANDE the lower limit is set to N>12. The lower limit is given by the trigger condition described in chapter 3.1.2 of the "KCDC User Manual".

5.2.2 ARRIVAL TIMES PER STATION (GARRIVAL)

The '**GRANDE Arrival Times**' are given with a resolution of 1ns/bin. Fig 5.2.2 shows the 'arrival time'– distribution.

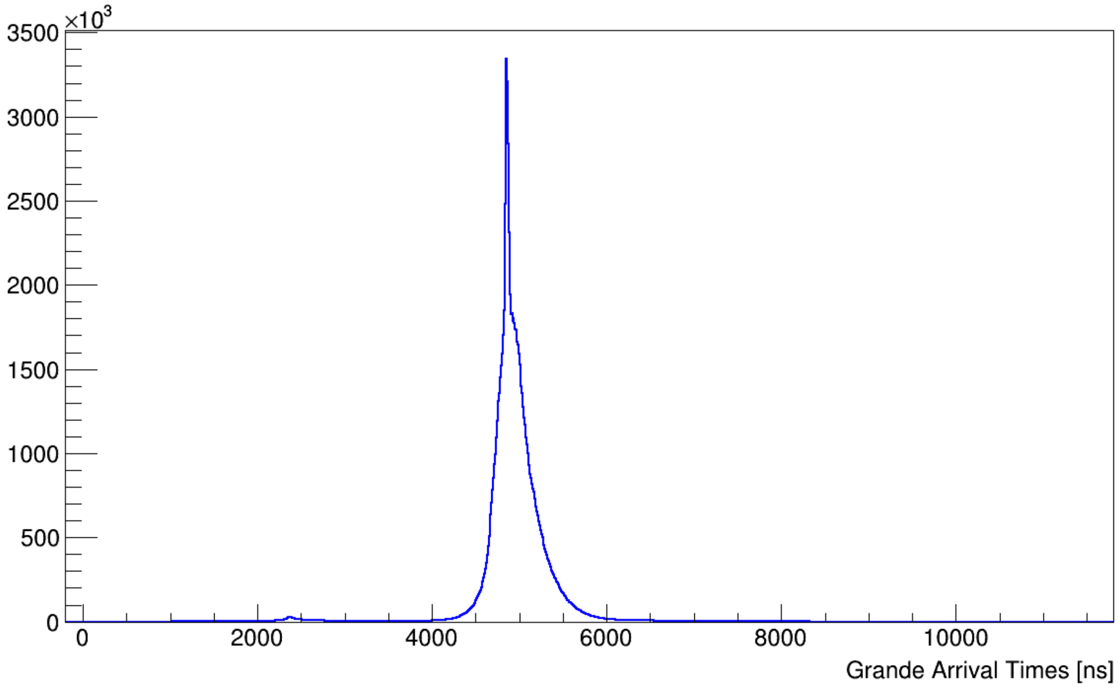


fig. 5.2.2 *GRANDE Arrival time distribution*

5.2.3 STATION ID (GARRIVALS)

The station ID holds the information of the location of the respective detector station. The transformation from the station ID to the GRANDE coordinates of the respective Grande detector station is in detail described in chapter 8.5 and Appendix B. Fig 5.2.3 shows the distribution of station IDs of the active detector stations. The structure is mostly caused by the area cut for the effective area in the core position of the GRANDE showers where some stations are outside these limits.

Note: This value is always shipped if the 'GRANDE Arrival Times' Quantity is selected but only in root and hdf5 files not in ASCII.

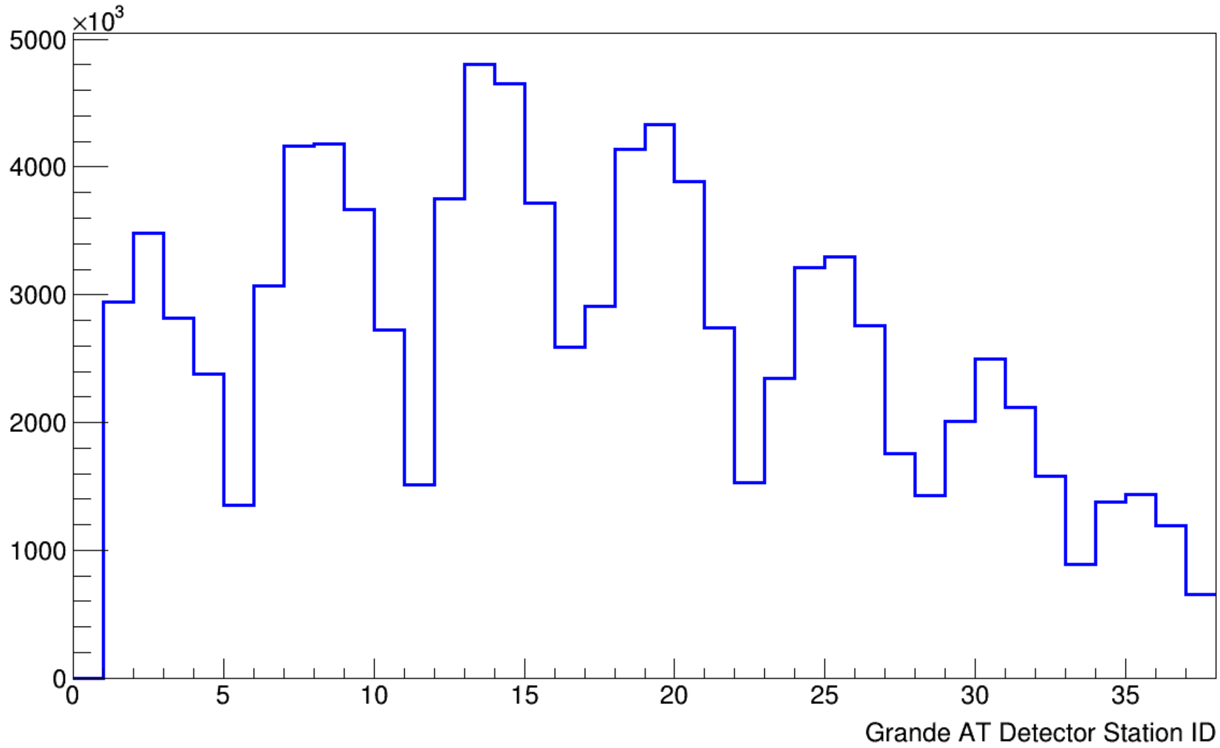


Fig. 5.2.3 *Distribution of station IDs for GRANDE detector stations with valid arrival times*

5.2.4 Example

An example for the arrival time distribution of one event is given in fig 5.2.4. The warmer the colour the bigger the time difference which usually corresponds to larger zenith angles. The arrival time distribution and the large difference in the arrival time of about 1400ns indicate that the shower is coming from north-east direction at a zenith angle of about 25°.

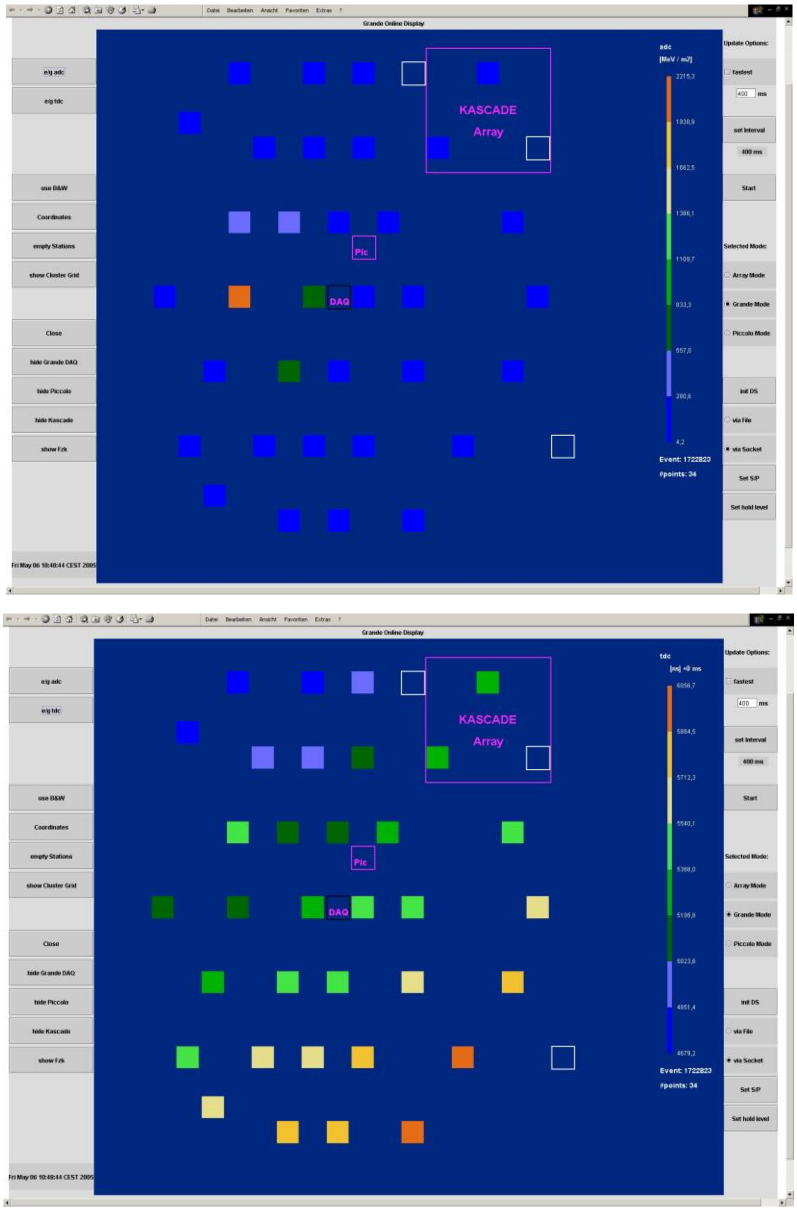


fig. 5.2.4 *Grande event No. 1722823 from 6.5.2005; energy deposit (left), arrival times (right)*

6 LOPES DATA IN KCDC

As described in detail in chapter 2.7 of the 'KCDC User Manual', the measured air showers from the radio antenna array LOPES (**LO**far **P**rototyp**E** **S**tation), are not part of the KASCADE main data stream. Nevertheless, they got a time stamp from the KASCADE trigger system to merge the measured data offline.

From the observables obtained in the analysis we choose 26 to be published in KCDC, which can be selected and mostly applied cuts on via the KCDC Data Shop as **Quantities**.

LOPES Quantity	Description	Unit	ID
Measuring Data			
EfieldMaxAbs	maximum atmospheric electric field as measured by e-field mill	*V/m*	EfieldMaxAbs
Azimuth E-W	azimuth of LOPES CC beamforming reconstruction (East-West)	*°(degree)*	AzL_EW
Azimuth N-S	azimuth of LOPES CC beamforming reconstruction (North-South)	*°(degree)*	AzL_NS
Elevation E-W	elevation of LOPES CC beamforming reconstruction (East-West)		ElL_EW
Elevation N-S	elevation of LOPES CC beamforming reconstruction (North-South)		ElL_NS
CCheight E-W	amplitude of smoothed cross-correlation beam (East-West)	*µV/m/MHz*	CCheight_EW
CCheight N-S	amplitude of smoothed cross-correlation beam (North-South)	*µV/m/MHz*	CCheight_NS
Xheight E-W	amplitude of X-beam (East-West)	*µV/m/MHz*	Xheight_EW
Xheight N-S	amplitude of X-beam (North-South)	*µV/m/MHz*	Xheight_NS
rmsCCbeam E-W	RMS of CC beam in noise window (East-West)	*µV/m/MHz*	rmsCCbeam_EW

LOPES Quantity	Description	Unit	ID
Measuring Data			
rmsCCbeam N-S	RMS of CC beam in noise window (North-South)	*µV/m/MHz*	rmsCCbeam_NS
Number of Antennas E-W	number of antennas contributing to CC beam (East-West)	*(number of)*	*NCCbeamAntennas_EW*
Number of Antennas N-S	number of antennas contributing to CC beam (North-South)	*(number of)*	*NCCbeamAntennas_NS*
ConeAngle E-W	cone angle rho of hyperbolic wavefront reconstructed with CCbeam forming (East-West)	*°(degree)*	*coneAngle_EW*
ConeAngle N-S	cone angle rho of hyperbolic wavefront reconstructed with CCbeam forming (North-South)	*°(degree)*	*coneAngle_NS*
Eta E-W	slope parameter of exponential LDF (East-West)	*1/m*	*eta_EW*
Eta N-S	slope parameter of exponential LDF (North-South)	*1/m*	*eta_NS*
Eps E-W	amplitude parameter of exponential LDF (East-West)	*µV/m/MHz*	*eps_EW*
Eps N-S	amplitude parameter of exponential LDF (North-South)	*µV/m/MHz*	*eps_NS*
Geomag Angle	angle between geomagnetic field and COMBINED shower axis	*°(degree)*	*geomag_angle*
Reconstruction	Reconstruction used as Input for LOPES: A = KASCADE ('array') 65; G = Grande 71		*reconstruction*
LOPES Component Identifier	used to identify an event with Lopes data 1 = with LOPES data 0 = no LOPES data		*Lopes_Comp_ID*

LOPES Quantity	Description	Unit	ID
Measuring Data			
Height	amplitude of pulse (after correction for noise)	*µV/m/MHz*	*height[30]*
Distance	distance of antenna position to shower axis	*m*	*dist[30]*
EnvelopeTime	time of maximum envelope	*ns*	*envelopeTime[30]*
Polarization	alignment of antennas (EW or NS)		*polarization[30]*

The [30] in the last 4 quantities denotes that these are data arrays, which hold information for every single LOPES antenna. The plots shown in this chapter are only examples. So, applying user cuts either in the KCDC Data Shop or in your own analysis can change these spectra drastically.

6.1 EFILEDMAXABS

The e-field has been measured on KASCADE site in the centre of the LOPES array by means of an e-field mill 3m above the ground taking data every second.

During fair weather, the electric field at ground level has a value between -100 V/m and -200 V/m. Occurring small changes are slow, with a typical time scale in the range of minutes. However, when a thunderstorm occurs, the conditions change quite drastically. Ground field strength may exceed ± 20 kV/m. In addition, lightenings are visible as discontinuities in the recorded data. Thus for ‘normal’ analyses a cut is applied removing events recorded during conditions with an e-field higher than 3000 V/m.

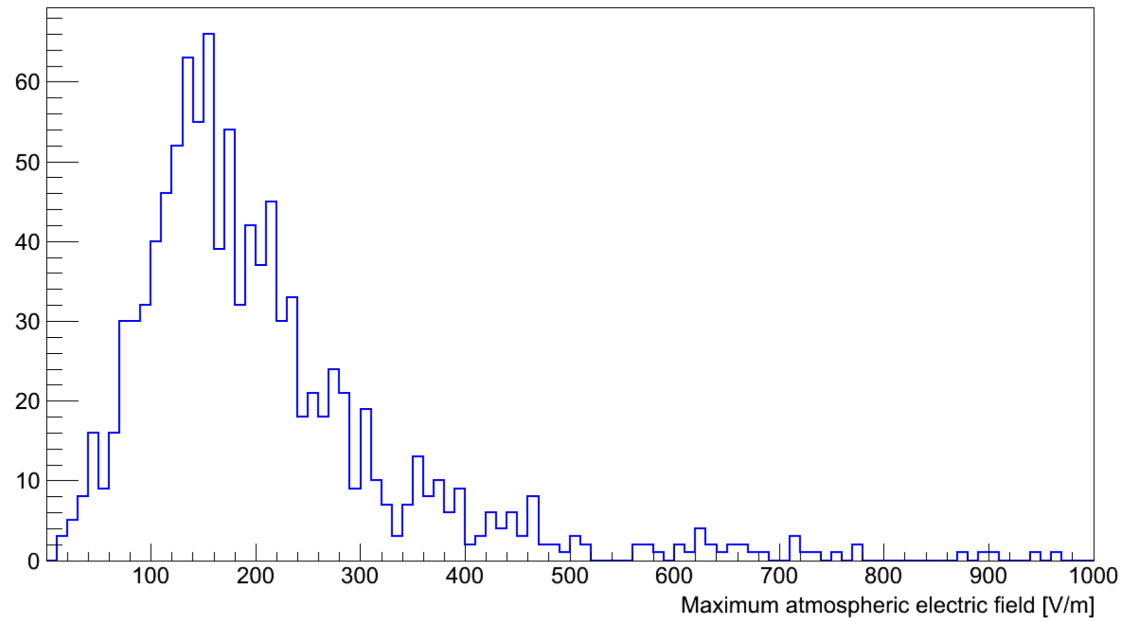


fig. 6.1.1 ***E-filed distribution as measured by the e-field mill (absolute value)***

6.2 AzL_EW & AzL_NS and ElL_EW & ElL_NS

AzL_EW/AzL_NS and ElL_EW/ElL_NS describe the direction reconstructed using the cross-correlation beamforming for the east-west and north-south aligned antennas respectively. The LOPES coordinates are defined analogously to KASCADE. So the Azimuth AzL is defined as Az, the Elevation ElL equals 90°-Ze, so ElL=90° points upwards. During the maximization of the CC-beam, the assumed arrival direction of the shower is changed according to a defined grid on the sky. This grid is centred on the arrival direction reconstructed by the Combined Data Analysis, which is used as a starting value. For each arrival direction the expected time difference of the LOPES time trace is calculated and corrected for. Then the CC-beam is maximized using a simplex fit varying the direction, see also 6.3. Thus, the reconstructed direction is those yielding the maximum value for the smoothed CC-beam.

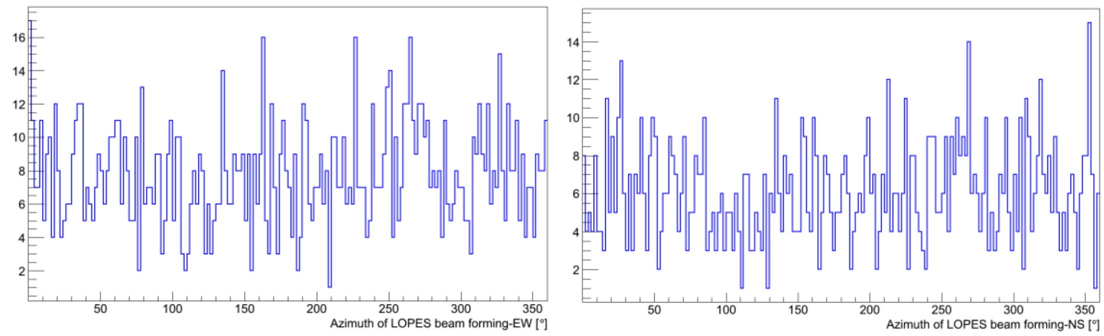


fig. 6.2.1 ***Azimuth of LOPES CCbeam forming reconstruction***
left: East-West orientation; right: North-South orientation

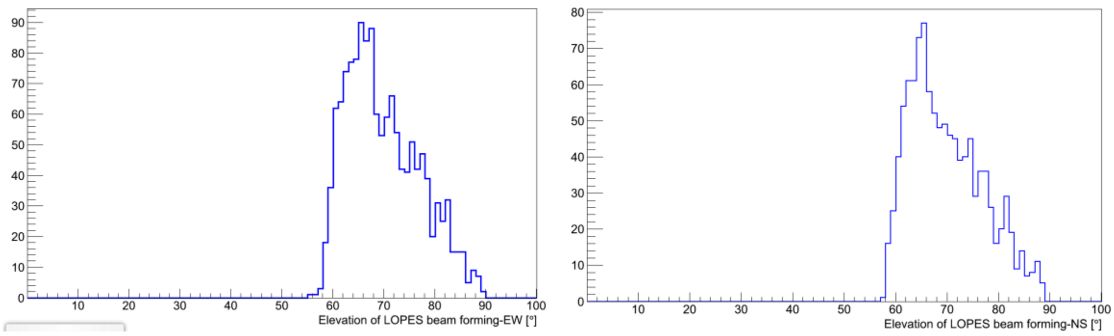


fig. 6.2.2 ***Elevation of LOPES CCbeam forming reconstruction***
left: East-West orientation; right: North-South orientation

6.3 CCheight_EW & CCheight_NS and rmsCCbeam_EW & rmsCCbeam_NS

The CCheight is the maximum value of the smoothed cross-correlation beam, which is determined as follows:

According to the arrival direction and the distance of the air shower, a geometrical delay of the signal in each antenna is calculated. The shower core is given by COMBINED. This delay depends on the shape of the radio wave front. Investigations on measured and simulated radio signals show that a hyperbolic shape is the best approximation for the radio wave front. For larger distances this hyperboloid approaches an asymptotic cone. Such a hyperbolic shape is parametrized using the following formula:

$$c\tau(d, z_s) = \sqrt{(d sin\rho)^2 + (cb)^2} + z_s cos\rho + cb$$

With the lateral distance of the antenna to the shower axis d, the distance of the antenna to the shower plane z_s and the two parameters ρ for the opening angle of the asymptotic cone and b describing the time offset between the hyperboloid and the asymptotic cone at the shower axis. According to the expected arrival time of the signal, calculated with the formula above, the time traces are shifted in such a way that after the shift the radio signal is seen at the same time in all antennas.

Then the directional sensitivity of the antenna is considered by the application of the antenna gain. In a final step the cross correlation beam, CC-beam, is calculated using the following equation:

$$cc(t) = \pm \sqrt{\left| \frac{1}{N_{pairs}} \sum_{i=1}^{N_{Ant}-1} \sum_{i>j}^{N_{Ant}} s_i(t) \cdot s_j(t) \right|}$$

With N_{Ant} being the number of Antennas, N_{pairs} the number of unique pairs, the time t and the time-shifted traces of the particular antennas $s_{i/j}(t)$.

To suppress fine structure coming from the bandpass filtering, the CC beam is smoothed by applying a block-averaging over the lengths of three raw samples (37.5 ns; which contain more than three samples when upsampling is used in the reconstruction). Then the arrival direction and the cone angle ρ are changed according to a defined grid on the sky and the CC-beam is maximized using a simplex fit. The arrival direction reconstructed by COMBINED is used as a starting value.

Finally, a Gaussian function is fitted to the CC-beam, which provides the information on time and height of the CC-beam. The time is used to identify the time of the signal in the individual antennas, see 6.11.

Additionally, the RMS value of the CC-beam is calculated which is a measure for the background. The ratio of the CCheight and the RMS of the CC-beam, thus, is a signal-to-noise ratio. A cut is applied rejecting events with a low ratio, where the threshold is 14 or lower, depending on the number of antennas contributing to the CC-beam:

$$CCheight/rmsCCbeam > 14 * \sqrt{(N_{Ant}/30)}$$

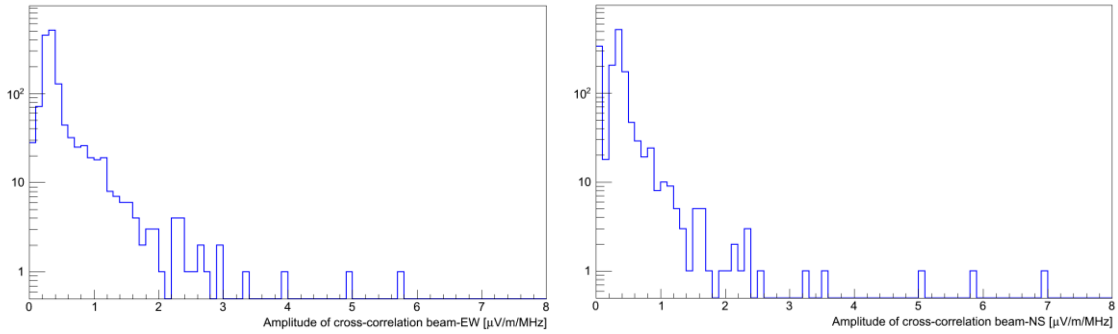


fig. 6.3.1 ***Amplitude of smoothed cross correlation beam***
left: East-West orientation; right: North-South orientation

6.4 XHEIGHT_EW & XHEIGHT_NS

The X-beam or excess beam x(t) is calculated from the block averaged (BA) CC-beam and power beam like:

$$x(t) = cc(t) \cdot \left| \frac{\langle cc(t) \rangle_{BA}}{\langle p(t) \rangle_{BA}} \right|$$

Then a Gaussian function is fitted providing the height of the X-beam. The Xheight is used as quality cut for the radio data: The fraction of power in the CC-beam compared to the total power is an important quantity for the quality of LOPES events and can be determined from the ratio of the Xheight divided by the CCheight, which needs to be between 0.8 and 1.5 for an event to pass the following quality cut:

$$0.8 > \frac{Xheight}{CCheight} < 1.5$$

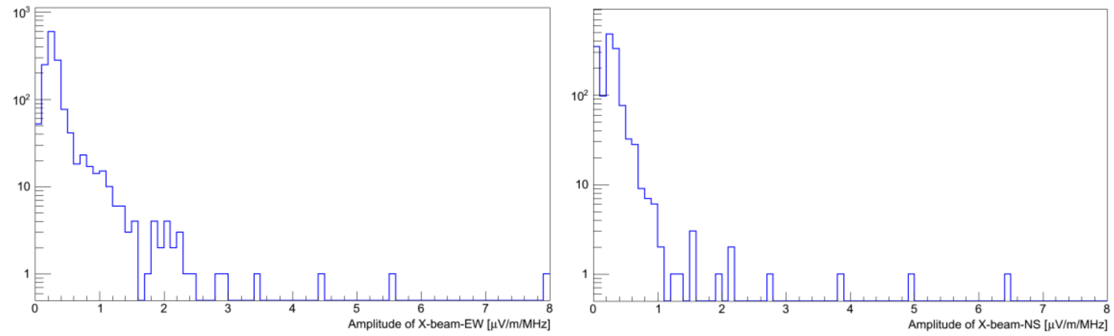


fig. 6.4.1 *Amplitude of X-beam*

left: East-West orientation; right: North-South orientation

6.5 NCCBEAMANTENNAS_EW NCCBEAMANTENNAS_NS

NccbeamAntennas_EW/NS are the numbers of antennas used for the calculation of the CC-beam, so the number of antennas NAnt.

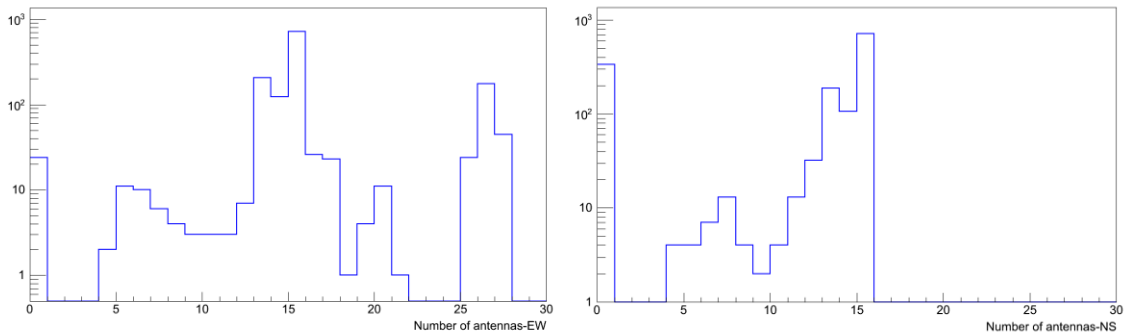


fig. 6.5.1 *number of antennas contributing to CC beam*

left: East-West orientation; right: North-South orientation

This number can vary due to different setups, inactive or malfunctioning antennas.

6.6 CONEANGLE_EW & CONEANGLE_NS

The cone angle is derived during the maximization of the CCbeam, see 6.4. The radio wavefront is approximated by a hyperbolic shape, which is parametrized, using the following formula:

$$c\tau(d, z_s) = \sqrt{(dsin\rho)^2 + (cb)^2} + z_s cos\rho + cb$$

With the lateral distance of the antenna to the shower axis d, the distance of the antenna to the shower plane z_s and the two parameters ρ for the opening angle of the asymptotic cone and b describing the time offset between the hyperboloid and the asymptotic cone at the shower axis. The cone angle corresponding to the maximized CCbeam is given here.

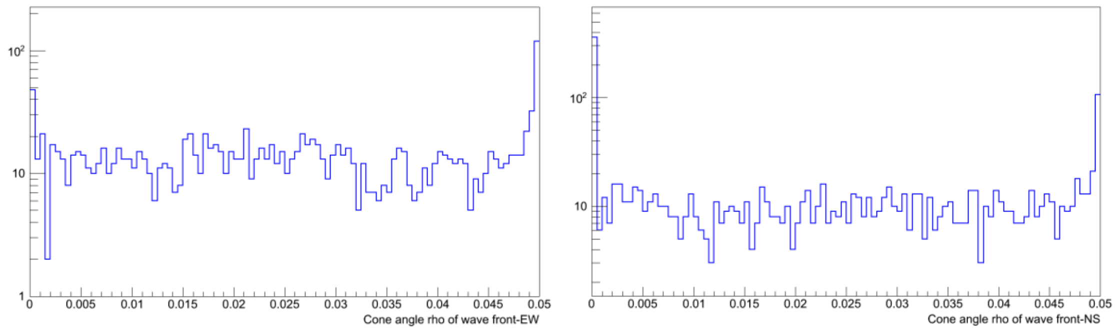


fig. 6.6.1 ***cone angle rho of hyperbolic wave front***
left: East-West orientation; right: North-South orientation

6.7 ETA_EW & ETA_NS AND EPS_EW & EPS_NS

The lateral distribution, i.e. the amplitude of the radio pulse ε vs the lateral distance to the shower axis d of each antenna, is fitted using an exponential function:

$$\varepsilon(d) = \varepsilon_{100} \cdot exp[-\eta(d - 100m)]$$

with the fit parameters ε_{100} which is the amplitude eps_EW/NS at 100m axis distance, and η which is the lateral slope eta_EW/NS.

This is a simplified assumption assuming a radial symmetry of the radio signal around the shower axis, neglecting the small asymmetry due to the interference of the geomagnetic and Askaryan effects for the radio emission. The lateral distribution also neglects that for some showers, the radio amplitude first rises until reaching the distance of the Cherenkov cone and decreases only for larger distances. For those events dominated by the rising inner part of the lateral distribution, thus, a negative value of η is expected.

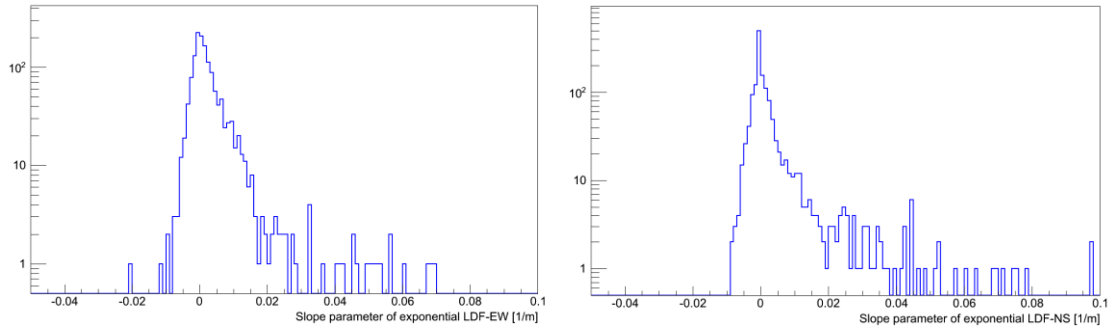


fig. 6.7.1 *η slope parameter of exponential LDF*
left: East-West orientation; right: North-South orientation

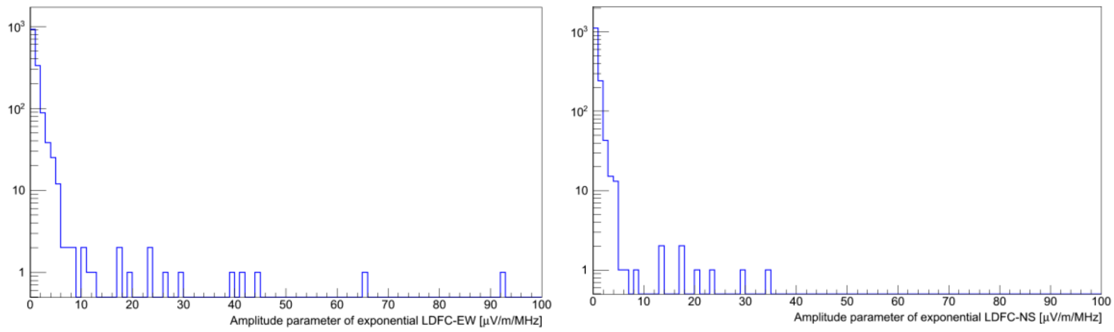


fig. 6.7.2 *ε amplitude parameter of exponential LDF*
left: East-West orientation; right: North-South orientation

6.8 GEOMAG_ANGLE

The radio signal strongly depends on the angle between the shower axis and the Earth's magnetic field called geomagnetic angle. Therefore, this value is provided here. It is calculated using the COMBINED shower coordinates Az and Ze and the direction of the magnetic field in Karlsruhe which is along BAz = 0° and BZe = 64.4°.

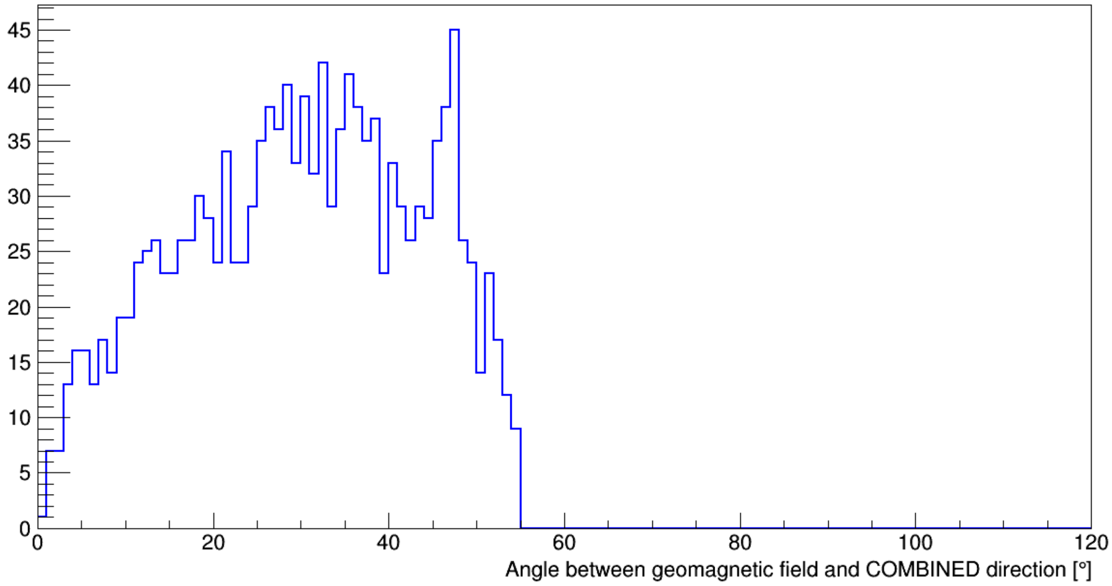


fig. 6.8.1 *angle between geomagnetic field and COMBINED shower axis*

6.9 RECONSTRUCTION

The reconstruction parameter indicates which shower reconstruction has been used. For this analysis only the combined reconstruction is available. Thus the reconstruction parameter can only be C=67 for COMBINED.

6.10 LOPES COMP ID

The LOPES Component Identifier is a technical parameter to select events with Lopes Radio data directly. The 'LopesCompID' for all Lopes events is set to '1'. If you want to select only data sets with Lopes content you will have to apply a cut in the DataShop from '1' to '1' for the LopesCompID.

6.11 HEIGHT

The height is the amplitude of the radio pulse at each antenna after noise correction and after pulse identification using the time of the CC-beam maximum. The calculation of the CC-beam enables the identification of the pulse induced by the air shower: RFI, e.g., induced by the KASCADE-Grande detectors, is usually incoherent while the radio pulse from an air shower is coherent. The CC-beam therefore allows identifying the time of the air-shower signal. This information is used to get the radio pulse amplitude measured by individual antennas. With the timing information from the CC-beam, the maximum pulse amplitude in each antenna is determined by choosing the nearest local maximum of the Hilbert envelope of the trace (i.e., the nearest local maximum of the instantaneous amplitude). For the amplitude at the individual antennas also the influence of noise is considered: Investigations show that noise can increase or decrease the signal depending on the signal-to-noise ratio and a noise correction is applied individually for each antenna correcting for the average effect at the corresponding signal-to-noise ratio.

Note: on the quantity 'LOPES Height' no cuts can be applied

Handling the data array '**Lopes Height'** quantity mostly requires some additional information either on the absolute coordinates of the detector station or on the distance to the reconstructed shower core. Therefore the quantity '**heightS'** is always supplied with the '**height'** values. Furthermore, the number of detector stations with valid '**height'** information ('**heightN'**) is provided as well.

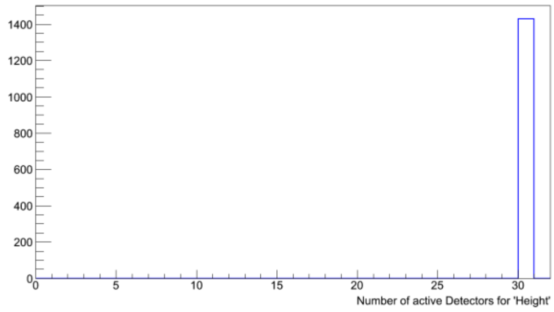
Thus, if the quantity '**Lopes Height'** is selected in the KCDC DataShop you will always be supplied with the following data sets:

heightN	number of active LOPES detector stations for this event [0 … 30]
height	amplitude of the radio pulse [µV/m/MHz]
heightS	detector station ID used for **height** [1…30]

6.11.1 Number of LOPES detector stations with Height Information (heightN)

The distribution of '**heightN'** is shown in fig. 6.11.1. (left).

Note: This value is always shipped if the 'LOPES Height' Quantity is selected but only in root and hdf5 files not in ASCII.



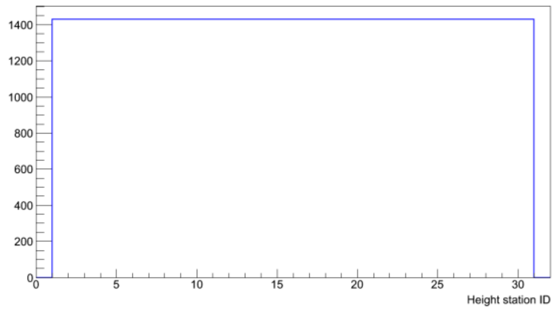


fig. 6.11.1. *Distribution of the number of active detector stations for 'LOPES Height' (left) and the distribution of station IDs (right)*

6.11.2 Station ID (HeightS)

The station ID holds the information of the location of the respective detector station. The transformation from the station ID to the LOPES coordinates of the respective LOPES detector station is in detail described in Appendix C. Fig 6.11.1 (right) shows the distribution of station IDs of the active detector stations.

Note: This value is always shipped if the 'LOPES Height' Quantity is selected but only in root and hdf5 files not in ASCII.

6.11.3 Height per Station (Height)

The '**LOPES Height'** distribution is shown in fig 6.11.2.

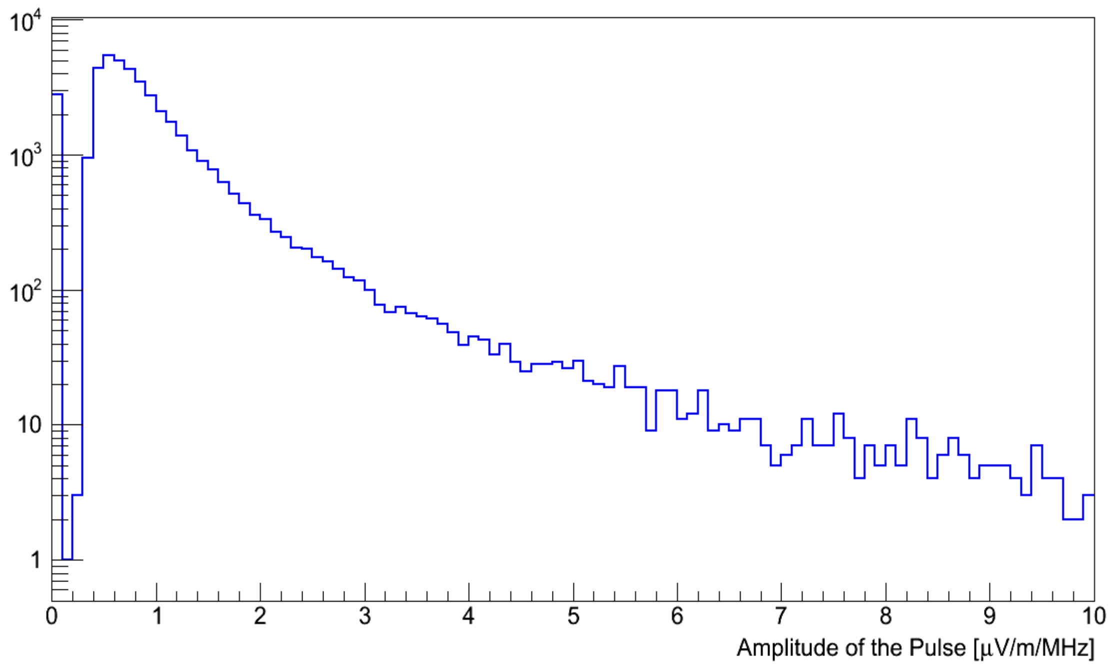


fig. 6.11.2 *amplitude of pulse after noise correction*

6.12 ENVELOPETIME

The envelope time is the time in the trace of each individual antenna at which the pulse amplitude (height) is determined. Consequently, this is the time of the local maximum of the Hilbert envelope closest to the signal arrival time determined by the CC-beam. Typically, it can be up to a few 10 ns earlier or later than this CC-beam time.

Note: on the quantity 'LOPES Envelop Time' no cuts can be applied.

Handling the data arrays '**Lopes Envelope Time'** quantity mostly requires some additional information either on the absolute coordinates of the detector station or on the distance to the reconstructed shower core. Therefore the quantity '**envelopeTimeS'** is always supplied with the '**envelopeTime'** values. Furthermore, the number of detector stations with valid '**envelopeTime'** information ('**envelopeTimeN'**) is provided as well.

Thus, if the quantity '**Lopes envelopeTime' is** selected in the KCDC DataShop you will always be supplied with the following data sets:

envelopeTimeN	number of active LOPES detector stations for this event [0 … 30]
envelopeTime	Time of maximum of envelope [ns]
envelopeTime S	detector station ID used for **envelope Time** [1…30]

6.12.1 NUMBER OF LOPES DETECTOR STATIONS WITH ENVELOPETIME INFORMATION (ENVELOPETIMEN)

The distribution of ‘**envelopeTimeN’** is shown in fig. 6.12.1. (left).

Note: This value is always shipped if the ‘LOPES envelopeTime’ Quantity is selected but only in root and hdf5 files not in ASCII.

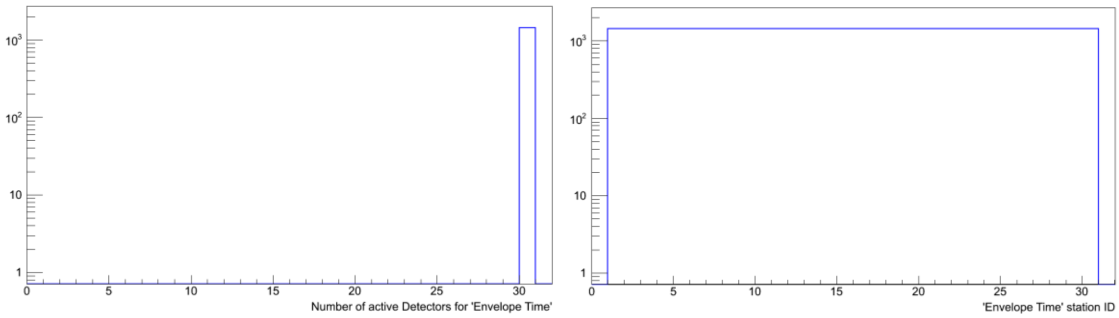


fig. 6.12.1. *Distribution of the number of active detector stations for ‘LOPES envelopeTime’ (left) and the distribution of station IDs (right)*

6.12.2 STATION ID (ENVELOPETIMES)

The station ID holds the information of the location of the respective detector station. The transformation from the station ID to the LOPES coordinates of the respective LOPES detector station is in detail described in Appendix C. Fig 6.12.1 (right) shows the distribution of station IDs of the active detector stations.

Note: This value is always shipped if the ‘LOPES EnvelopeTime’ Quantity is selected but only in root and hdf5 files not in ASCII.

6.12.3 ENVELOPE TIME PER STATION (ENVELOPETIME)

The ‘**LOPES envelopeTime’** distribution is shown in fig 6.12.2.

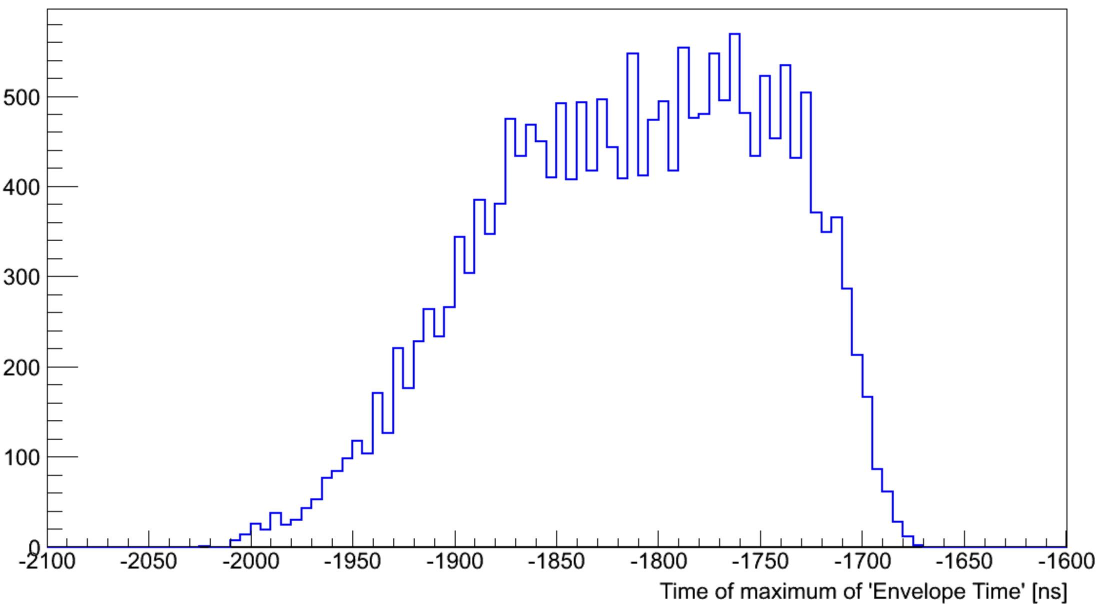


fig. 6.12.2 ***time of maximum of envelop***

6.13 DISTANCE TO SHOWER AXIS

The distance **d** is the lateral distance of the antenna position of a single antenna to the shower axis, reconstructed with LOPES, which is used for the reconstruction of the lateral distribution (the standard wave front reconstruction is by the CC-beam, which turned out to be more stable than the reconstruction using the envelopeTime and distance in the individual antennas).

Handling the data array '**Lopes Distance'** quantity mostly requires some additional information either on the absolute coordinates of the detector station or on the distance to the reconstructed shower core. Therefore the quantity '**distanceS'** is always supplied with the '**distance'** values. Furthermore, the number of detector stations with valid **distance** information ('**distanceN'**) is provided as well.

Thus, if the quantity '**Lopes Distance'** is selected in the KCDC DataShop you will always be supplied with the following data sets:

distN	number of active LOPES detector stations for this event [0 … 30]
dist	distance to the shower axis [m]
distS	detector station ID used for **dist** [1…30]

6.13.1 Number of LOPES detector stations with Distance Information (distN)

The distribution of distN is shown in fig. 6.13.1. (left).

Note: This value is always shipped if the 'LOPES Distance' Quantity is selected but only in root and hdf5 files not in ASCII.

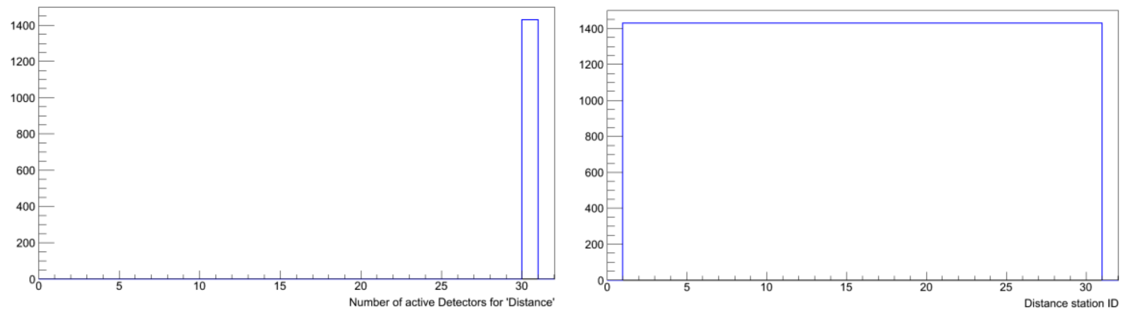


fig. 6.13.1. *Distribution of the number of active detector stations for 'LOPES Distance' (left) and the distribution of station IDs (right)*

6.13.2 Station ID (distS)

The station ID holds the information of the location of the respective detector station. The transformation from the station ID to the LOPES coordinates of the respective LOPES detector station is in detail described in Appendix C. Fig 6.13.1 (right) shows the distribution of station IDs of the active detector stations.

Note: This value is always shipped if the 'LOPES Distance' Quantity is selected but only in root and hdf5 files not in ASCII.

6.13.3 Distances per Station (dist)

The '**LOPES Distance'** distribution is shown in fig 6.13.2.

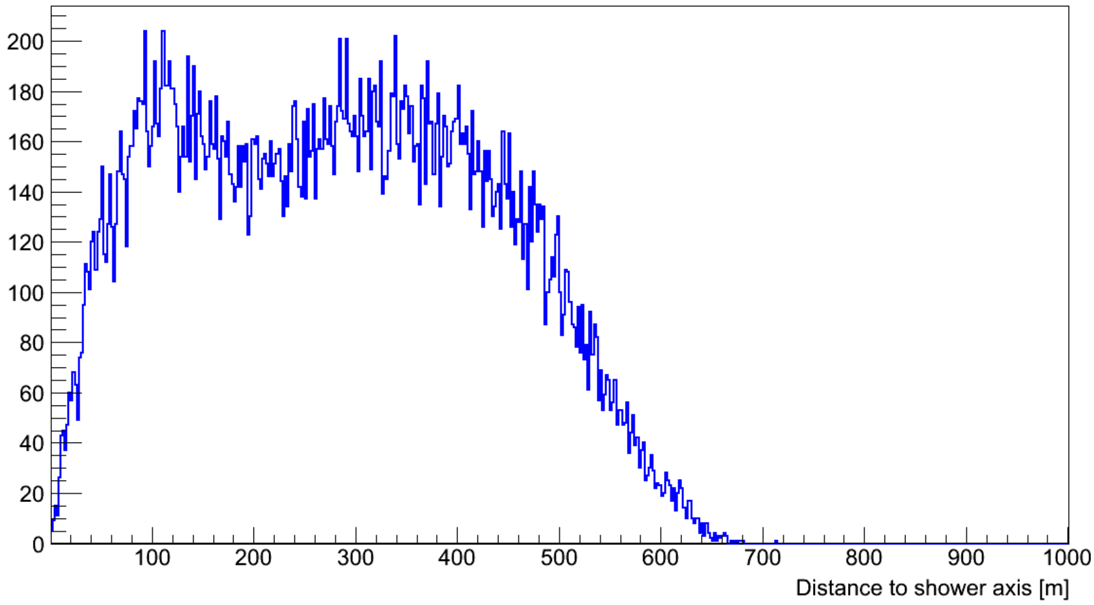


fig. 6.13.2 *distance of antenna position to shower axis*

6.14 Polarization

The polarization is the alignment of the antenna, which is either EW – along the east-west axis or NS – along the north-south axis. This value can change for different setups. For both sets of antennas (EW) and (NS), the reconstruction is run separately and independently from each other.

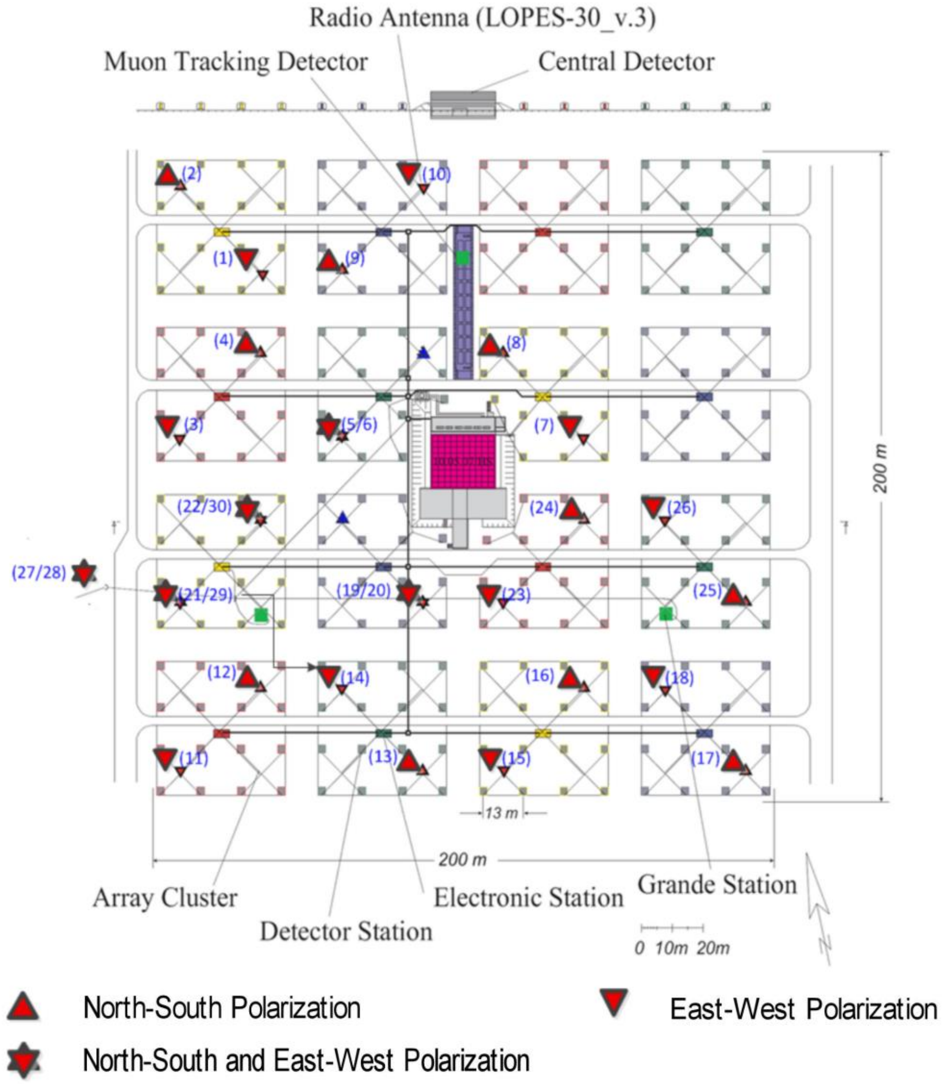


Fig. 6.14.1 *Polarization of the LOPES-30 radio antennas*

In the data sets provided to the users, '0' denotes an antenna polarization in North-South direction, '1' stands for East-West polarization. Five antenna positions are equipped with antennas in both directions (see also app. C).

7 GENERAL DATA IN KCDC

The 'general' data describe measuring conditions, like Air Temperature and Air Pressure, as well as Event conditions like Event Time and Run Number necessary for correction and unique identification purposes.

7.1 EVENT TIME (DATETIME, GT, MT)

In KASCADE an event is stored when the trigger condition is fulfilled (details see chapter 3 of th "KCDC User Manual"). As all events recorded are triggered either by the KASCADE Array or by the GRANDE Array, these conditions are based on the layout of the two detector arrays. For the KASCADE Array the 252 detector stations are subdivided in 16 clusters (4x4 stations each, the 4 inner clusters have on 15 stations each). The trigger condition is fulfilled when at least one cluster has recorded a signal above a certain threshold. For the GRANDE Array the trigger condition is fulfilled when at least all seven stations of one trigger hexagon have recorded a signal above the threshold. The time of the first trigger either from KASCADE or from GRANDE is stored as the event time.

The event time is always given in UTC which is affected with an offset of -2h for summer time (CEST) and -1h for winter time (CET). As a redundant time information we use at KASCADE the *Unix Time,* a system timestamp counting the number of seconds elapsed since 1. January 1970 (midnight UT), which is internally referenced as *Global Time (GT)*. To get a high precision time stamp the so called Micro Time (MT) information is used. Based on the cycle of a 5 MHz clock which is reset and synchronised every second, we obtain an accuracy of +/- 200 ns for the event time.

For a better accuracy of the absolute time, we utilize the Global Positioning System (GPS), which is a high-precision satellite navigation system. The absolute accuracy is better than 1 µs.

With an integration time of 200 ns, the electronics of each station is ready for the next measurement after about 1.2 µs. Taking into account the trigger rate of about 4 Hz, the total dead time due to the data acquisition is 5 µs.

Due to the difference of the cable lengths between the array clusters, i.e. transmission path, the differences in the transmission time are determined by a time calibration and corrected for.

7.2 AIR TEMPERATURE AND PRESSURE (T, P)

The earth's atmosphere has a small influence on the development of the extensive air showers and thus cannot be neglected, in particular for anisotropy studies of cosmic rays. Thus, data can be corrected for effects of temperature and pressure on an event-by -event basis in analyses.

The meteorological data are received from the Institute of Meteorology and Climate Research at KIT. The measurements are taken from sensors placed 2m above ground level for the temperature readings and 1.5m above ground for the air pressure measurements on site of KIT, Campus North, about 1 km from the KASCADE experiment. All climate observables were recorded every 10 minutes.

The figure 7.2.1 presents the distribution of the temperature between 2004 and 2010. The spectrum shows, that the seasonal variation and the distribution is stable.

In general, the number of charged particles decreases exponentially after their shower maximum and it varies with the zenith angle, as well as with the atmospheric pressure. Therefore, the attenuation can be described with the attenuation length λ_N by:

$$\langle N_e(X)\rangle \propto exp\left(-X_0/\lambda_{N_e}\cos\Theta\right)$$

where $N_e(X)$ is the number of electrons of the extensive air shower at the slant depth $X[g/cm^{-2}]$. The X_0 is a definite initial atmospheric depth after the maximum of the longitudinal shower development and it is 1020 g/cm^{-2} at KASCADE

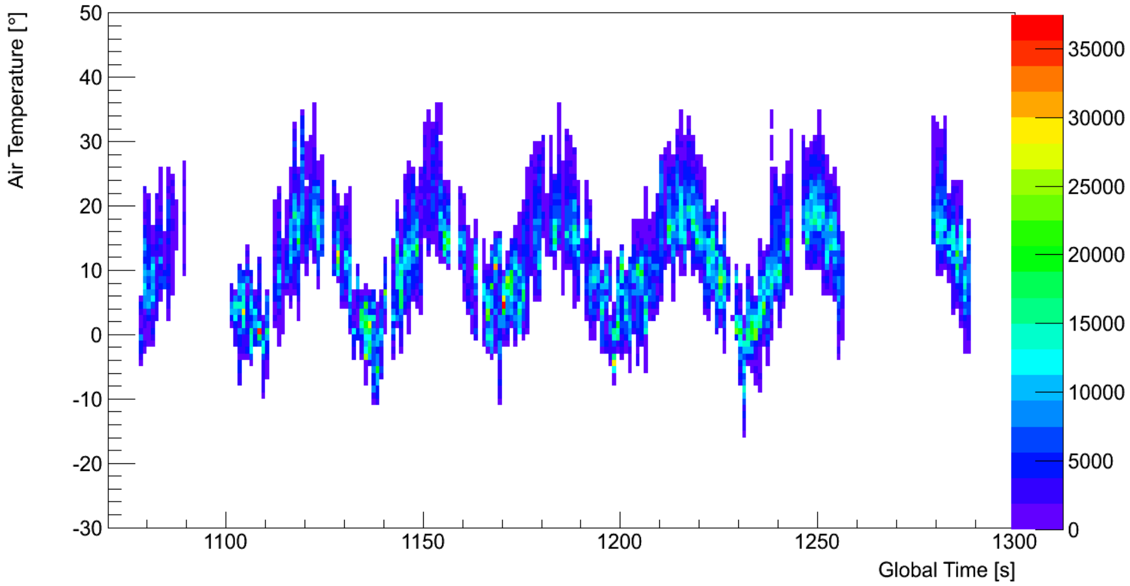


Fig. 7.2.1 ***The spectrum of the temperature as a function of the Global Time measured at ground level for the time period 8.3.2004 – 4.11.2010 in [10^6 s].***

A variation of the slant depth by the pressure $p(t)$ with an average atmospheric pressure p_0 is given by

$$X\big(p(t)\big) = \frac{X_0}{\cos\Theta} + \frac{p(t) - p_0}{g \cdot \cos\theta}$$

The fluctuation of the rate because of the pressure variation can be up to 20%. By means of tuning a polynomial function, the atmospheric influences on the rate can be well corrected.

The variation of the pressure for the measuring period 2004-2010 is given in fig 7.2.2.

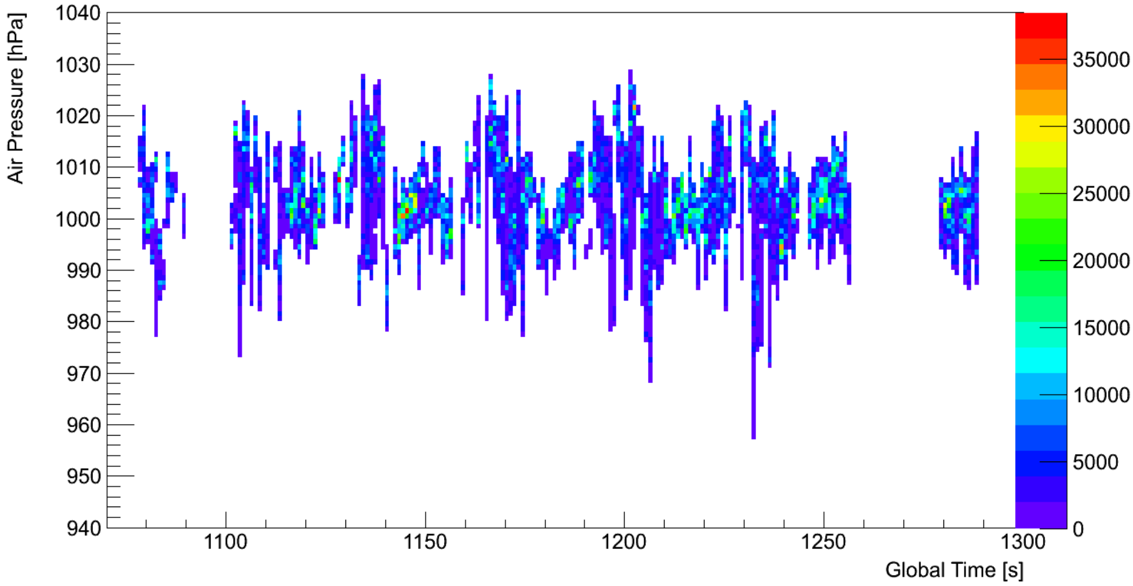


Fig. 7.2.2 *The spectrum of the air pressure as a function of the Global Time measured at ground level for the time period 8.3.2004 – 4.11.2010 in [10^6 s].*

7.3 Run Number & Event Number

Run Number and **Event Number** are two parameters, which characterise an event uniquely. They will always be supplied with the data sets. A run is in KASCADE defined as a set of events recorded under the same hardware conditions. An automatic procedure in the data recording system caused the data taking to stop and to start with a new run if the hardware conditions of one of the various detector components has changed, p.e. loss of one detector.

The Event Number starts at '1' with each run and is increased with every valid hardware trigger, which invokes data recording. KASCADE recorded within its lifetime more than 1.7 billion events of which only 15 million passed our quality cuts and could be reconstructed with the Combined Data Analysis method.

7.4 UUID

The **UUID (Universally Unique Identifier)** has been introduced to identify a single event by one unique string. This identifier is required to match the KCDC data with the data of the TAIGA/TUNKA experiments published within the KRADLC initiative (**K**arlsruhe-**R**ussian **A**stroparticle **D**ata **L**ife **C**ycle **I**nitiative).

A unique UUID represents an object independent from versions and the reference is immutable. Records that were once published in KCDC are frozen by versions, which means that even if the data are extended or changed the reproducibility is maintained.

8 DATA ANALYSIS HELPS

This chapter provides some valuable information on how to deal with the COMBINED data, based on our experience of data analysis.

8.1 EFFICIENCIES

COMBINED reaches its full detection- and reconstruction efficiency at around $\log(N_e)=5.5$ which corresponds roughly to a reconstructed energy of about $10^{15.5}$ eV. This implies that below this value you will have to deal with efficiency corrections and threshold effects. Some of these effects are described in chapter 3.

The study of the detector efficiency has been done by means Monte Carlo Simulations where the respective efficiency curves for proton- and iron-induced showers have been investigated. Fig 8.1.1 shows the combined trigger and reconstruction efficiency as a function of the true energy for events located in the KASCADE-Grande area with COMBINED area cuts applied. The picture indicates that trigger- and reconstruction reaches its full efficiency around $10^{15.8}$ eV reconstructed energy.

In fig 8.1.2 the “full efficiency cut" (solid line) is shown on top of the log10(Ne)-$\log10(N_\mu)$ distribution for simulated events located in KASCADE-Grande. On the left hand side for events with energies above the threshold of full efficiency and for all events on the right hand side.

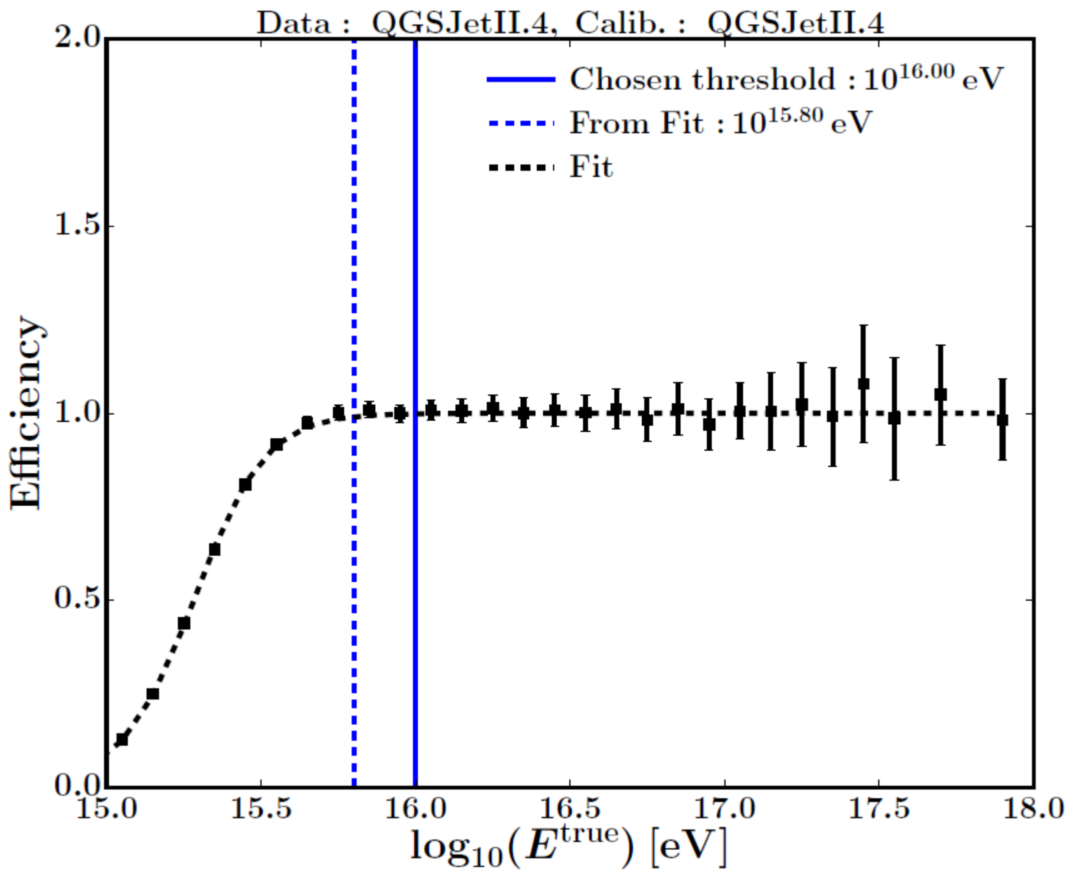


Fig. 8.1.1 *The combined trigger and reconstruction efficiency as a function of the true energy for events located in KASCADE-Grande (COMBINED area cut used) (from S.Schoo PhD)*

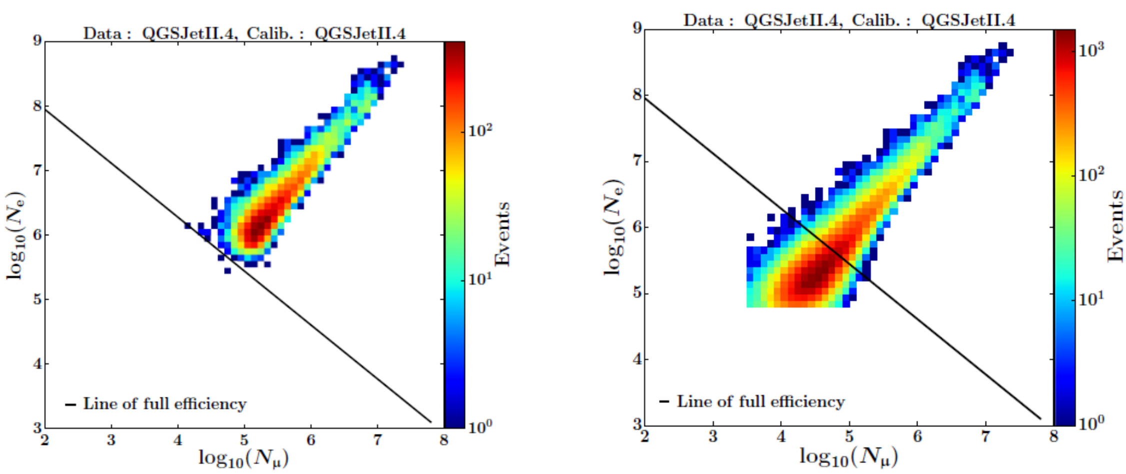


Fig. 8.1.2 *The "full efficiency cut" (solid line) on top of the log10(Ne)-log10(Nµ) distribution for simulated events located in KASCADE-Grande.; l.h.s. for events with energies above the threshold of full efficiency and for all events on the r.h.s. (from S.Schoo PhD)*

8.2 CUTS

Concerning applied cuts we distinguish between '**Data Selection Cuts'** and '**Advised Cuts'**. The first are already applied on the data published when filling the mongoDB (see chapter 2.4.), the latter are highly recommended.

8.2.1 DATA SELECTION CUTS

The '**Quality Cuts LOPES'** have mostly been applied while filling the KCDC database.

- **event is already part of KCDC DataShop**
  only events which were already in the KCDC DataShop are stored
- **reconstruction parameters from LOPES agree**
  only events where the core position and the incident angle reconstructed by the Combined Data Analysis and by LOPES analysis agree are stored

8.2.2 ADVISED CUTS

The '**Advised Cuts'** are strongly recommended by the KASCADE collaboration. They have been applied in most of our publications.

for LOPES:

- **EfiledMaxAbs < 3000 V/m;**
  the maximum E-field measured by the afield mill has to be <3000 V/m. Above this value the data are likely to be influenced by atmospheric disturbances like thunder-storms.

8.3 EXPERT'S ADVICES

Here are some advices, which we think are helpful for people doing analysis with the KCDC data.

- **be careful applying cuts on the quantity 'energy';**

  the quantity energy is a rough estimation based on the measured numbers of electrons (N_e) and the number of muons (N_μ) by means of an "Energy Estimator" who's parame-ters are deduced with help of a Monte-Carlo Simulation sets optimized for the zenith angle range 0° to 17° (see chapter 3.1.3). It would be advisable to cut on N_e or/and N_μ instead;

- **how to handle the quantities 'Energy Deposit' and 'Arrival Times';**

  the energy deposit values are only given when the station was working properly. Otherwise, the 'Station ID' (EDepositS) is missing as well as all data for the respective station. The deposit value '0' thus denotes a station, which was working but is not a part of the present event. If you are interested in the station coordinates please refer to chapter 8.4. and appendix-A. (section 8.5 and appendix-B for GRANDE respectively).

  Basically, the same applies for the quantity 'Arrival Times'. However, here only stations marked as active e/g-detectors with valid time information are taken into account.

- **the 'row_mapping' file**

  must always be used to match events from different detector components like 'combined' and 'lopes'. When a detector component is missing in the respective event the row_mapping entry is set to '-1';

  C++ code examples how to deal with the row-mapping file can be downloaded.

  For KCDC COMBINED data:
  https://kcdc.isp.kit.edu/static/txt/KCDC_analyze_COMBINED_example.C.gz ,
  for COMBINED simulation:
  https://kcdc.isp.kit.edu/static/txt/KCDC_analyze_COMBINED_simulations_example.C.gz .

8.4 Calculation of Array Detector Station Locations from ID

For the 'Energy Deposits', the 'μ-Energy Deposits' and the 'Arrival Times' in KASCADE, the position of the detector stations is given in so called 'Station IDs' which is a number between 1 and 252 for e/γ-detectors and 192 for μ-detectors. The allocation table and the python-code to calculate the real position of the KASCADE stations in KASCADE coordinates are given in appendix 'A'.

8.5 Calculation of GRANDE Detector Station Locations from ID

For the 'GRANDE Energy Deposits' and the 'GRANDE Arrival Times' the position of the detectors is given in so called 'Station IDs' which is a number between 1 and 37. The allocation table and to calculate the real position of the respective GRANDE station in KASCADE coordinates are given in appendix 'B'.

8.6 Disturbances from ANKA

ANKA is a Synchrotron Radiation Source and a Test Facility and KIT-CN, located in the south-western corner of the GRANDE detector array about 700m away from the centre of the KAS-CADE array. Due to scattered radiation, GRANDE measures a disturbance in the measurement during beam injection times and when the beam is dumped in the sense that the GRANDE trigger is activated and events highly inclined coming from south-west are reconstructed. These periods of time as well as times when ANKA was doing ‘machine physics’ were excluded from the data when filling the mongoDB.

9 COMBINED DATA SHOP

The KCDC COMBINED DataShop offers the same features as the KCDC DataShop in which the data from KASCADE, GRANDE, the central Calorimeter and LOPES were published.

9.1 COMBINED DATA SHOP OVERVIEW

To have access to the KCDC COMINED Data Shop you need to be a registered user as described in chapter 10 of the "KCDC User Manual". You enter the Data Shop via the **'Data Shops'** Menu Item on the KCDC Homepage (https://kcdc.iap.kit.edu/) where you can either submit a new request within the former '**KASCADE'** DataShop, or the newly added '**COMBINED'** DataShop. Furthermore, you can **'Review'** your earlier requests or select one of the '**Data Preselections'** for direct download.

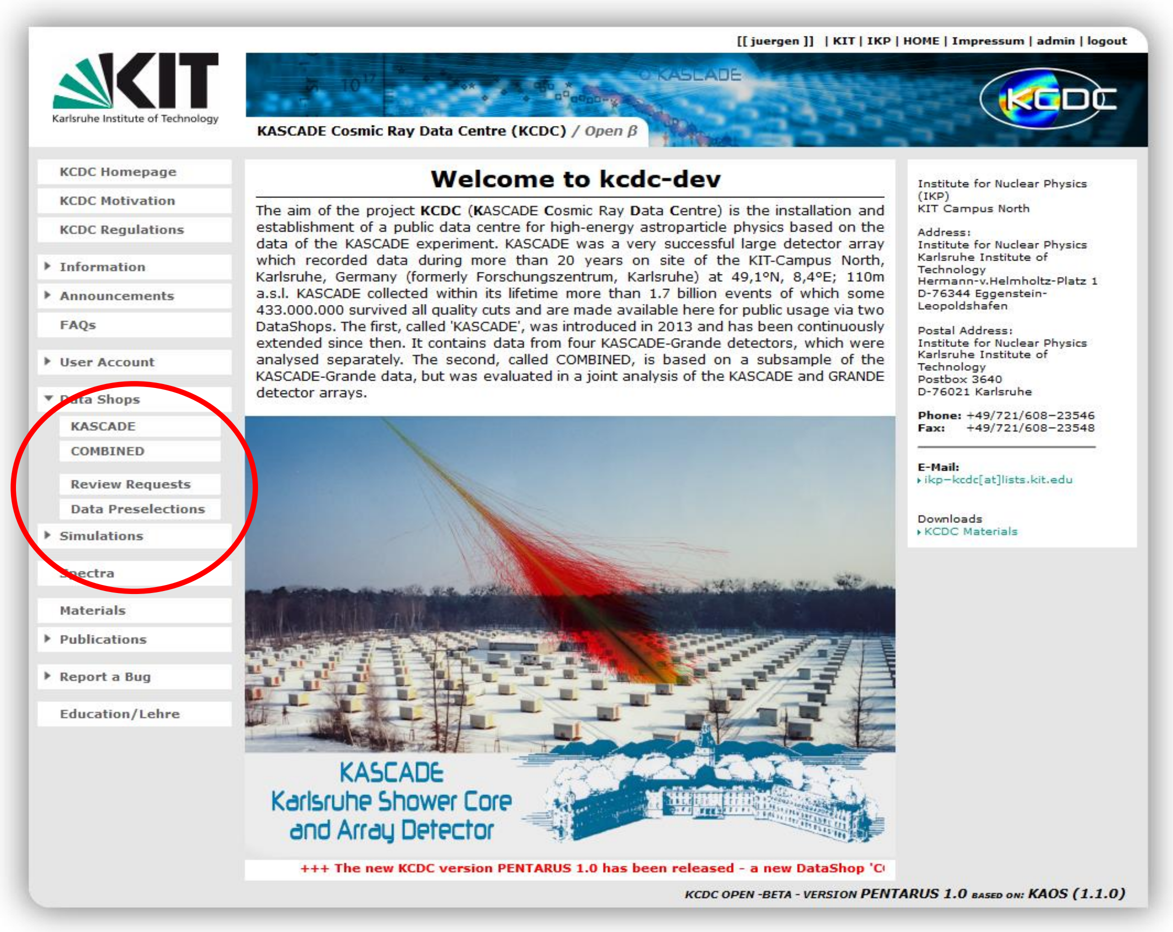


Fig. 9.1.1 *KCDC Homepage*

On the right hand side of the shop page invoked by *'COMBINED'* an information box (orange) is located with some simple helps to find your way through the KCDC Data Shop. This box changes when you *hover* for example over the detector components or later over quantities and cuts.

The link included at the bottom of the 'Welcome to the DataShop' info box will open this manual which holds detailed descriptions on the KASCADE and GRANDE detector components, quantities available and a short way how these quantities are gained from the parameters recorded with the KASCADE-G experiment.

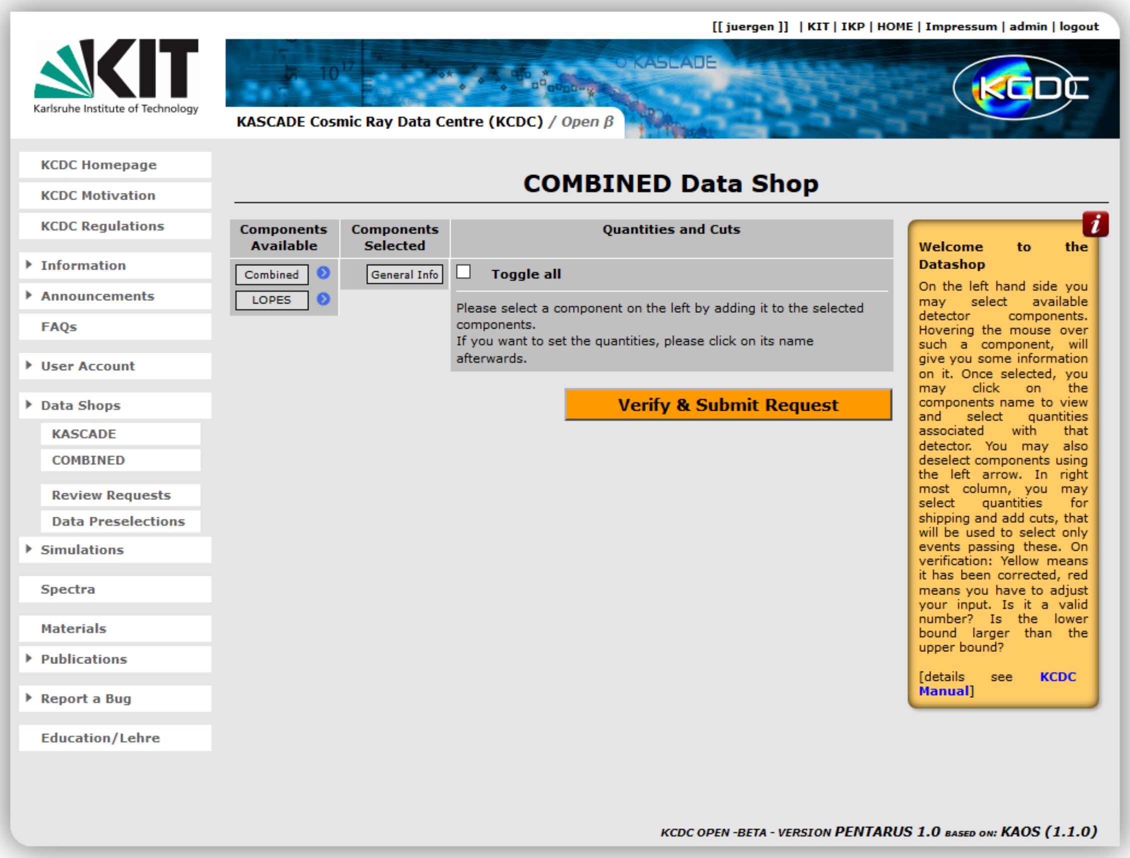


Fig. 9.1.2 *KCDC COMBINED DataShop intro page*

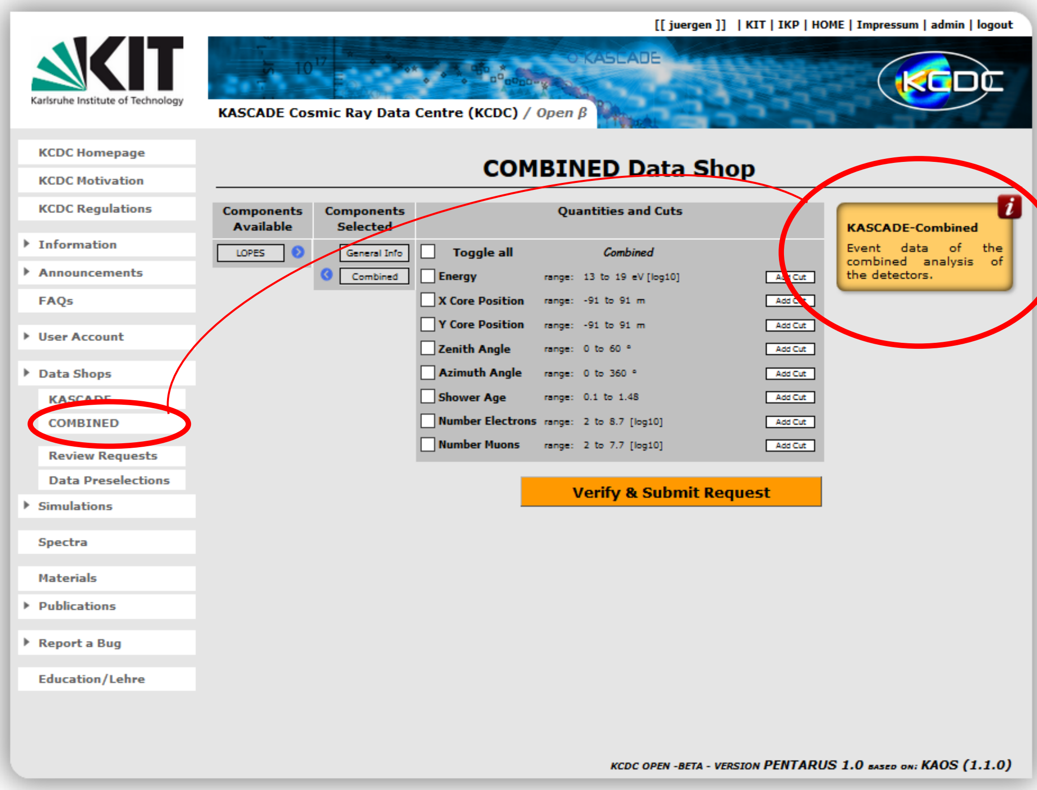


Fig. 9.1.3 *Info box with 'hover information' on detector components*

9.2 USER DEFINED SELECTIONS

The column 'Components Available' holds a list of the detector components of COMBINED DataShop from which quantities are presently available for selection and download. The column '*Components Selected*' holds a list of the detector components selected by the user to select quantities from and to apply cuts to.

To shift a component from '*Components Available'* to *'Components Selected'* and vice versa press the blue arrow of the respective component.

'*General Info'* holds all important event information. As the quantities *'Run Number'* and '*Event Number*' from '*General Info'* cannot be deselected '*General Info'* will always be selected too.

Pressing the *'General Info'* button opens a list of all available quantities with information on their ranges. Here you can select quantities for download and apply cuts by pressing the *'Add Cut'* button for the respective quantity.

For technical reasons all data arrays published from all components are placed in 'General Info'. No cuts can be applied on these quantities.

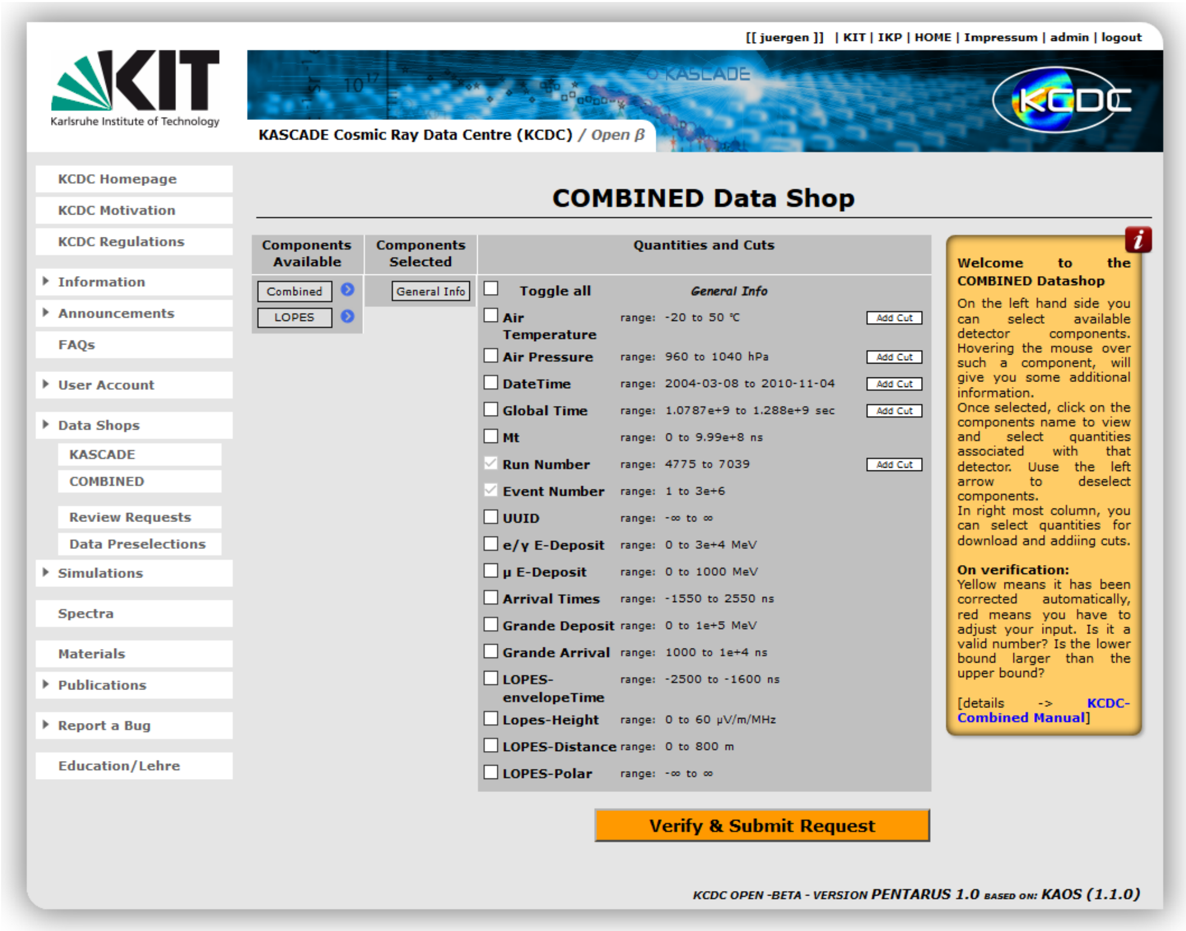


Fig. 9.2.1 *Quantities of 'General Info'; 'Run Number' and 'Event Number' are always selected*

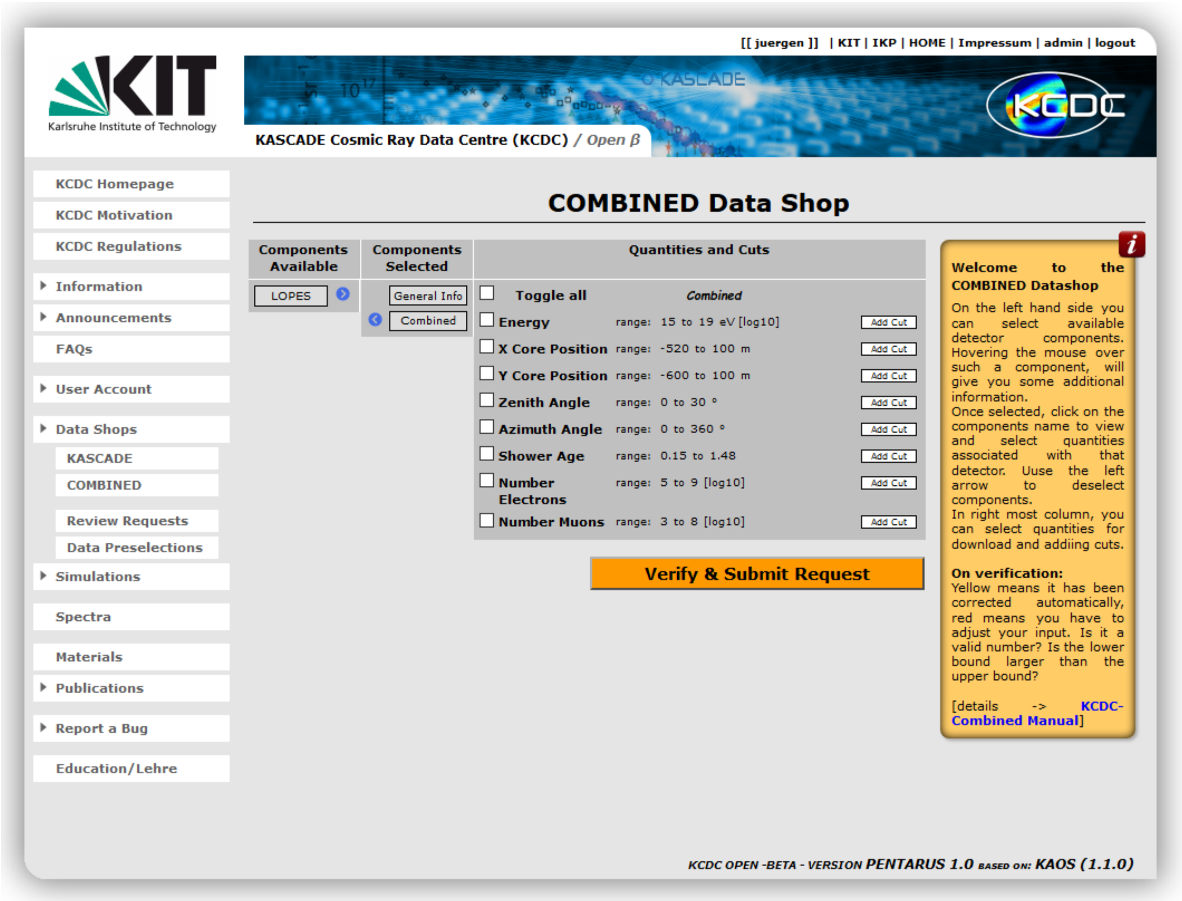


Fig. 9.2.2 *Quantities of 'COMBINED'*

9.3 USER DEFINED CUTS

To select only a subsample of the KASCADE data available you can apply your own cuts on most of the quantities. No cuts can be applied on quantities where the *'Add Cut'* Button is missing. We do not think that applying cuts makes sense for quantities like '*Micro Time'* or '*Event Number'*. We do as well not offer the cut option for arrays like '*Energy Deposits*' or '*Arrival Times*' at present.

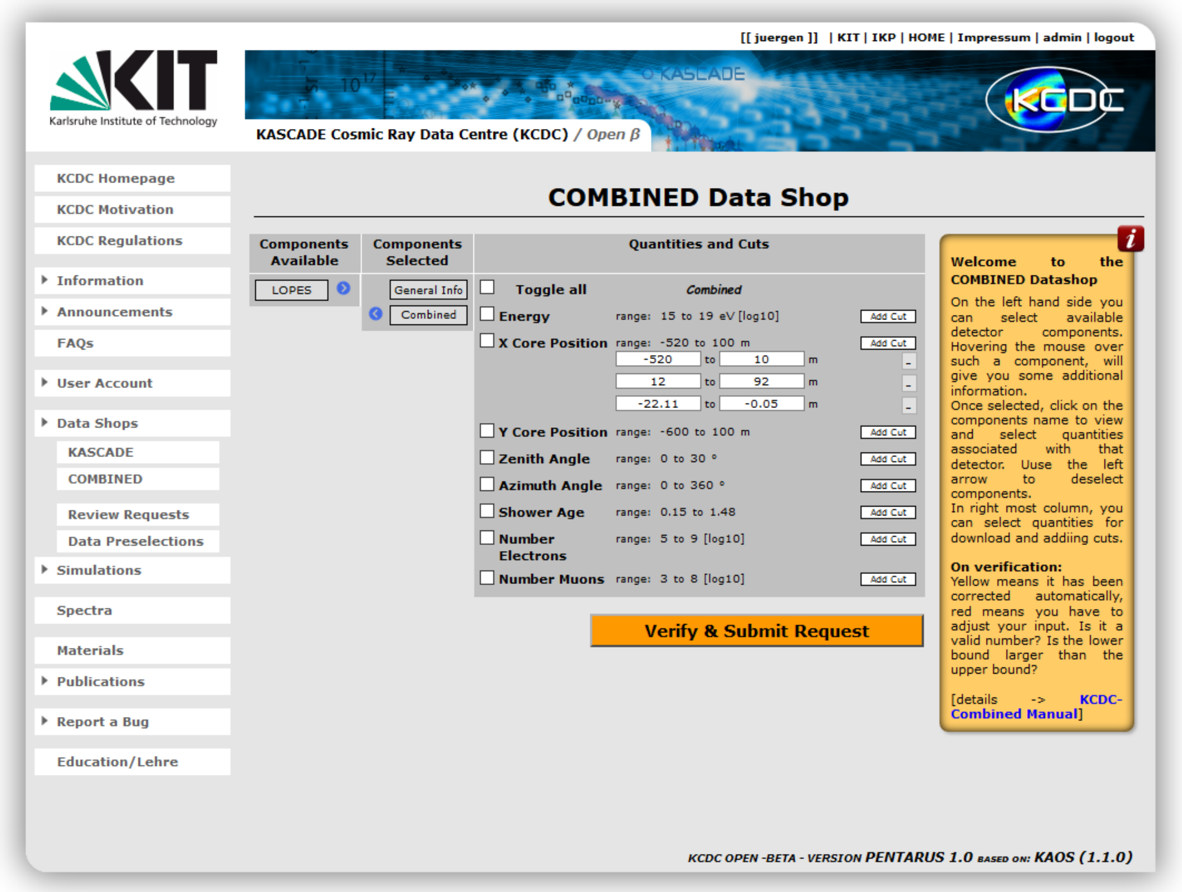


Fig. 9.3.1 *Applied cuts on 'X Core Position' with some example cuts*

To check and submit your requests press the *'Verify & Submit Request'* –Button.

The summary page gives an overview on your quantities selected for each detector component and on the cuts applied. Additional information on the cuts is provided as well in the last column like:

full range	the full data range for this quantity is selected
user cut	the user has applied cuts which are effective
corrected cut	the user has applied a cut outside the valid range, this cut has been corrected to be within the limits
obsolete now	the user has applied cuts which is beyond the limits, thus the range has been corrected and the selection covers now the full range of data

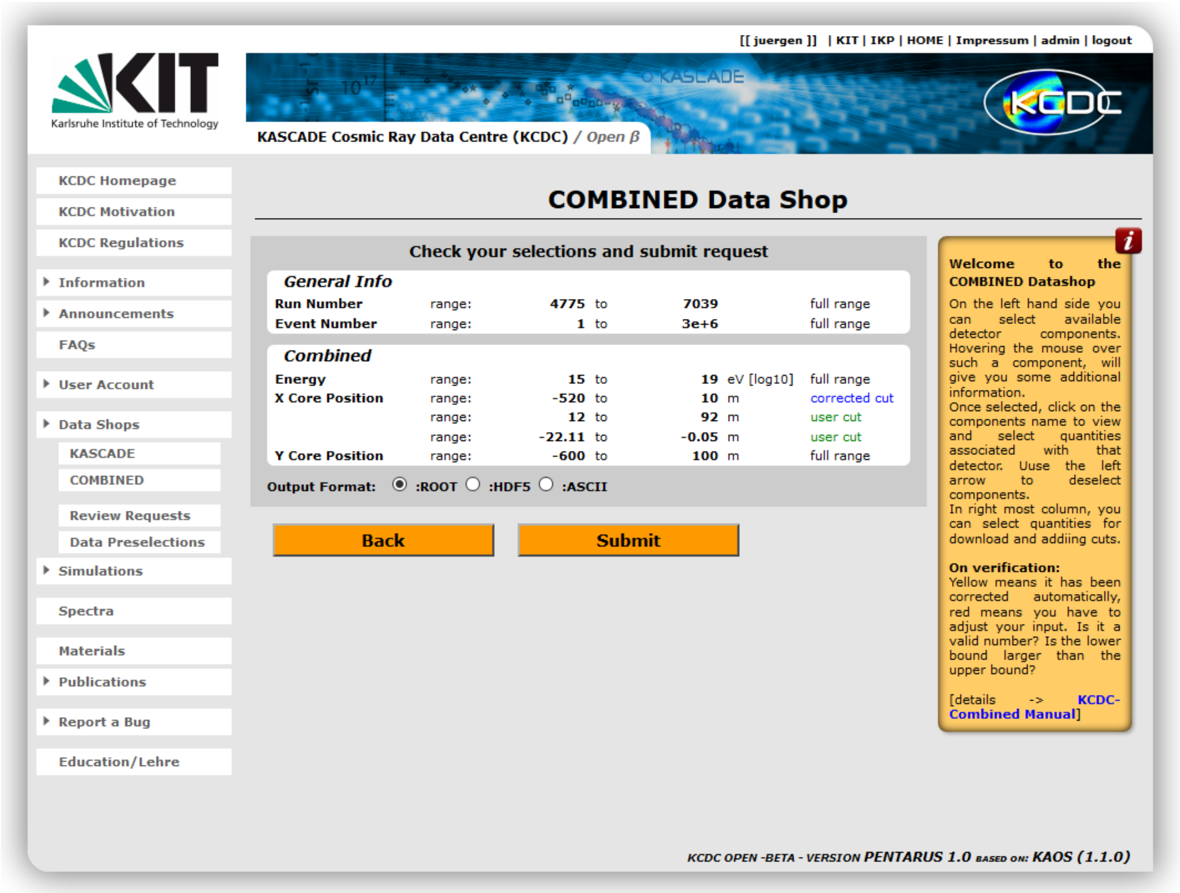


Fig. 9.3.2 *Check and submit your requests*

9.4 Job Submission and Review

After pressing the '*Submit*' –button you are redirected to your '*Review'* page, which holds a complete list of all your requests, submitted up to now. Details see chapter 9.5. '*Job Status Information'.*

9.5 Job Status Information

The '*Review'* page holds a complete list of all your requests submitted up to now from all DataShops and enables you to check the present status of your jobs submitted.

Displayed on this page are the date of your request, the data format selected for download and a job status information as described in the table below.

PENDING	job is in the queue to be started
STARTED	job has started
REVOKED	job has been cancelled by the user
SUCCESS	job has been successfully finished data are ready for download
FAILURE	job has failed for some reason
DL EXPIRED	the link to download your data sets is no longer valid

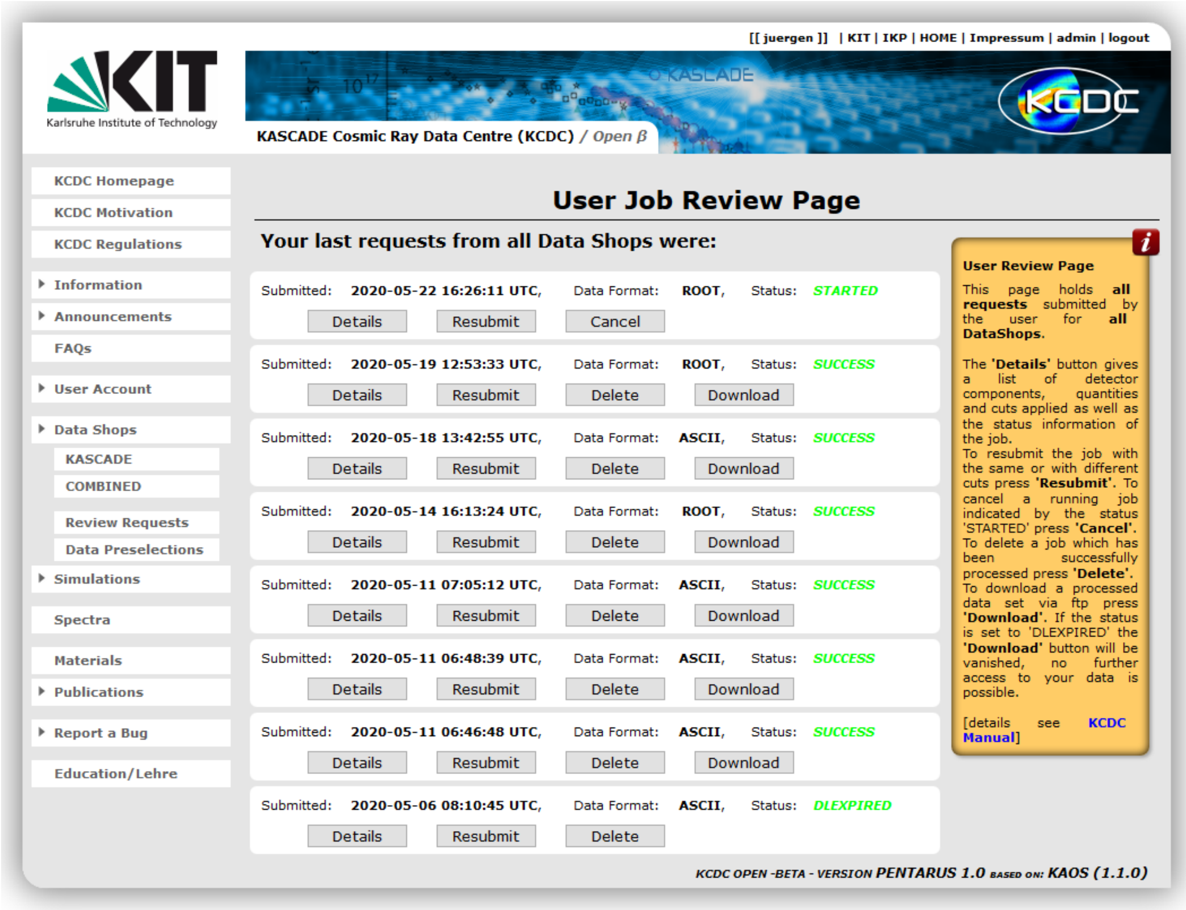


Fig. 9.5.1 *Job 'Review' -page*

On the '*Review*' -page you have several buttons to navigate through your requests. Some of these buttons may change according to the status of the job.

Button	Description	Visibility
Details	shows a list of your request as interpreted by the '*worker*'	switches to 'Hide' when pressed
Resubmit	offers the possibility to resubmit your job and change quantities, selections and cuts	always
Cancel	cancel the job	only while the job is running it will change to 'Delete' after the job has finished
Delete	delete the complete request	only when the job is finished
Download	get the link to download your data file	only when successfully finished and the download link has not expired

To get a more detailed list of your requests press the '*Details*' –button

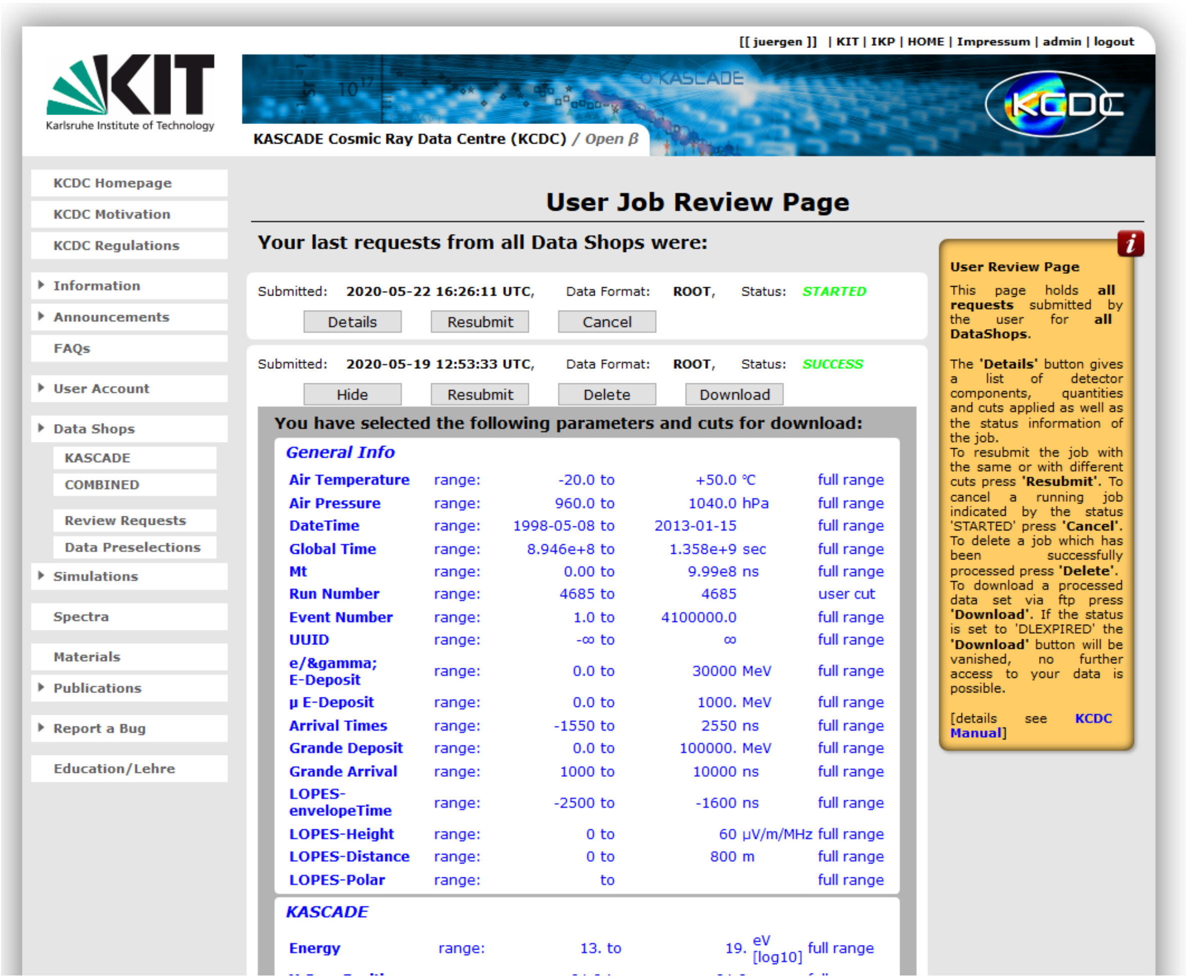


Fig. 9.5.2. *Details of user selections and cuts*

The information provided here may be different compared to the one displayed on the '*Verify & Submit Page'*. This is due do the fact that here only the effective ranges are displayed. Overlapping user defined cuts like in the above example are merged to one effective cut.

9.6 ADVICES TO USE THE DATA SHOP

Using the KCDC Data Shops efficiently requires a little background knowledge how the MongoDB is accessed and how 'Cuts' can speed up your request.

The present MongoDB, which holds the data for the release, PERNTARUS has a size of about 2 TB which makes it virtually impossible to offer the whole data sample for download. Therefore, restrictions on the user requests and on the file size are vital to guarantee a smooth running. The file size shipped to the user is limited to 50GB to keep the load and the network traffic manageable.

The query to the database uses indices for most of the quantities, which can be applied cuts on. We do presently not offer the possibility to cut on the data arrays because it would blow up the query time for the MongoDB enormously.

If you do not exactly know which quantities you need and what cuts to apply, download a small data sample like the one provided for such cases via the 'DataShops' 'Data Preselections' page. The sample 'COMBINED_SmallDataSample_..._ROOT' (or 'COMBINED_SmallDataSample_..._HDF5' or 'COMBINED_SmallDataSample_..._ASCII') holds about 390,000 events equally distributed over the whole measuring time which corresponds to 1/40th of the whole data sample and should enable you to check the effectiveness of your cuts.

Here are some hints:

- restrict the amount of data in your request by applying as many cuts as possible,
- cutting on energy (dismissing low energetic events) is the most effective cut (see table in chapter 4.1),
- the same applies basically for the N_e- and N_μ- quantities,

- download the sample data (390,000 events) to check your requirements and make a rough estimation on the number of events (and probably the file size) by applying your cuts before submitting a request,
- cutting on run number or time is sometimes not a good estimator to deduce the number of events for the whole data set because not all components have always been running,
- contact us in case you need some help iap-kcdc@lists.kit.edu.

9.7 TROUBLESHOOTING

9.7.1 … A GENERAL ERROR INFORMATION OCCURS

Some error information occurring while manoeuvring inside the DataShop is displayed in a red banner on top. Please act according the hints given there.

9.7.2 …THE SUBMITTED REQUEST DOES NOT START?

If you have submitted a request correctly but the status information on the 'Review Page' is not switching from 'pending' to 'started' please try again later. 'Pending' indicates that either there a several requests in the queue waiting to be executed, or that there is problem on the server side of KCDC. Wait for a couple of minutes and if the error persists, resubmit the request using the 'Resubmit' button. If the problem remains please report bugs to the KCDC-Team using the 'Report a Bug' feature.

9.7.3 …THE SUBMITTED REQUEST RETURNS WITH 'FAILURE'

If you have submitted a request and the job status information returns 'FAILURE' please try to resubmit the request using the 'Resubmit' button. If the problem remains please report bugs to the KCDC-Team using the 'Report a Bug' feature.

9.7.4 …DOWNLOADING A PRESELECTION RETURNS WITH ERROR 421

If you have created a new user account and you want to download a preselection from the DataShop's Data Preselection page, an error might occur indicating your home directory is not available (Error 421). This means that your download directory in the download area has not yet been created. A workaround to this problem is to start a ‘New Request’. Once the request is submitted your download directory is available and the Preselections can be transmitted.

10 Data Retrieval Process

10.1 Get Your Data

Once a request has been successfully processed the status will change to '*SUCCESS*' and a '*Download*' button will appear.

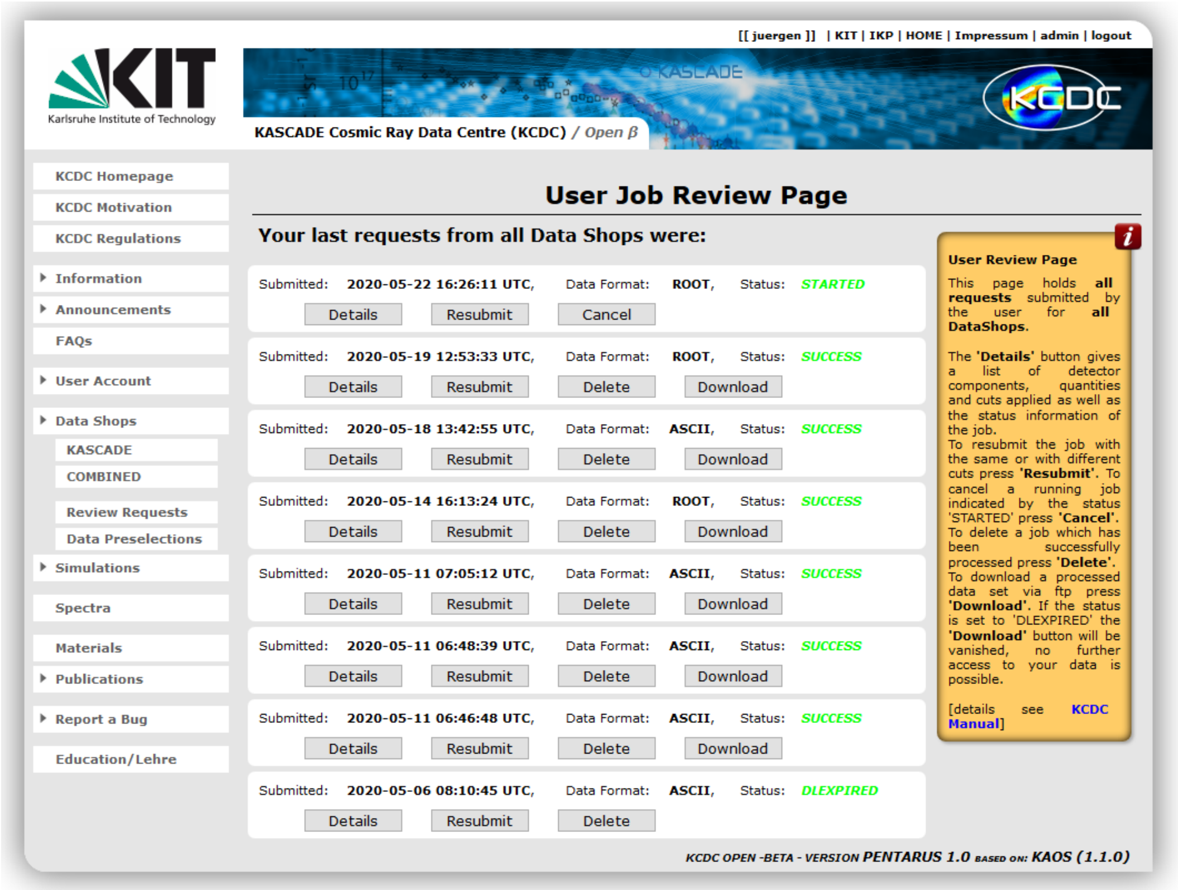


Fig. 10.1.1 *Request successfully finished → ready for 'Download'*

To start download you have to authenticate in the authentication window popping up. The download link will expire two weeks after the date of submission. After that, the status will switch to '*DL EXPIRED*' and the '*Download*' button will vanish.

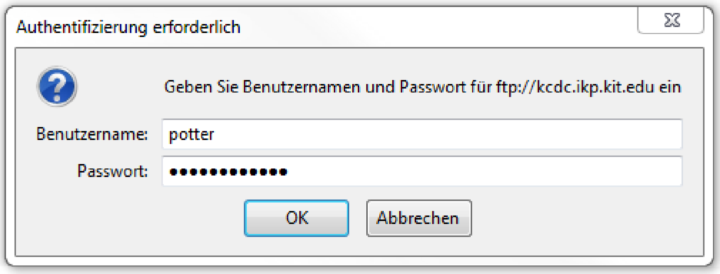


Fig. 10.1.2 *Download authentication window*

11 Data Preselections

If however you are interested in the 'Preselections' the DataShop navigation menu offers the option to download data samples directly without selecting quantities and applying cuts. This procedure has the advantage that no time consuming access to the mongoDB is necessary and you will get your data sample immediately. On the other hand, if you know exactly what data you need to perform your analysis it will be most of the time favourable to get your own appropriate data set even if it takes longer. The 'Data Preselections' page holds all predefined data sets from both DataShops, 'KASCADE-Grande' and 'COMBINED'. Details concerning the 'KASCADE-Grande' Preselections are described in the 'KCDC User Manual'.

11.1 Available COMBINED Data Preselections

The tables below show the 'COMBINED Data Preselections' available. The 'SmallDataSample_...' data set is meant to be used as a test sample for the user to check the requirements and the cuts. The column size should give you a rough estimation of the file space required. The 'Data Preselections' are invoked via the 'Data Shops' menu item.

11.1.1 COMBINED ASCII Preselections

ASCII Preselection		
Preselection Set Name	**Description**	**Size**
COMBINED_ReducedData_runs_4775-7039_ASCII	all COMBINED quantities; file name: C**OMBINED_ReducedData_runs_4775-7039_ASCII.zip** run range 4775-7039; 15,635,550 COMBINED events; no data arrays; no cuts applied,	1.2 GB
COMBINED_SmallDataSample_nA_runs_4775-7039__ASCII	Data sample with every 40th event of the whole COMBINED data set file name: **COMBINED_SmallDataSample_nA_runs_4775-7039_ASCII.zip** **390,888 events equally distributed;** runs range 4775-7039;	33 MB

ASCII Preselection		
Preselection Set Name	**Description**	**Size**
	all detector components; all quantities available; no data arrays; no cuts applied;	
COMBINED_HighEnergyData_ runs_4775-7039_ASCII	Data sample with all events > 15.7 [$\log_{10}$ eV] file name: **COMBINED_HighEnergyData_ runs_4775-7039_ASCII.zip** all quantities; run range 4775-7039; 1,738,231 events; no data arrays; Energy cut 15.7 – 19.0[$\log_{10}$ eV]	157 MB
COMBINED_LOPES_runs_5534-6821_ASCII	Data sample with LOPES radio events file name: **COMBINED_LOPES_ runs_5534-6821_ASCII.zip** run range 5534-6821; 1430 LOPES events; no data arrays; no cuts applied,	258 kB

11.1.2 COMBINED ROOT PRESELECTIONS

ROOT Preselection		
Preselection Set Name	**Description**	**Size**
COMBINED_ReducedData_runs_ 4775-7039_ROOT	all COMBINED quantities; file name: **COMBINED_ReducedData_ runs_4775-7039_ROOT.zip** run range 4775-7039; 15,635,550 COMBINED events; no data arrays; no cuts applied,	1.2 GB

ROOT Preselection		
Preselection Set Name	**Description**	**Size**
COMBINED_SmallDataSample_ nA_runs_4775-7039_ROOT	Data sample with every 40th event of the whole data set file name: **COMBINED_SmallDataSample_ nA_runs_4775-7039_ROOT.zip** **390,888 events equally distributed;** runs range 4775-7039; all detector components; all quantities available; no data arrays; no cuts applied;	33 MB
COMBINED_SmallDataSample_ wA_runs_4775-7039__ROOT	Data sample with every 40th event of the whole data set file name: **COMBINED_SmallDataSample_ wA_runs_4775-7039_ROOT.zip** **390,888 events equally distributed;** runs range 4775-7039; all detector components; all quantities available; including data arrays; no cuts applied;	376 MB
COMBINED_HighEnergyData_ runs_4775-7039_ROOT	Data sample with all events > 15.7 [$\log_{10}$ eV] file name: **COMBINED_HighEnergyData_ runs_4775-7039_ROOT.zip** all quantities; run range 4775-7039; 1,738,231 events; no data arrays; Energy cut 15.7 – 19.0[$\log_{10}$ eV]	15 MB
COMBINED_LOPES_nA _runs_5534-6821_ROOT	Data sample with LOPES radio events file name: **COMBINED_LOPES_nA_ runs_5534-6821_ROOT.zip** run range 5534-6821; 1430 LOPES events; no data arrays; no cuts applied,	333 kB

11.1.3 COMBINED HDF5 PRESELECTIONS

HDF5 Preselection		
Preselection Set Name	**Description**	**Size**
COMBINED_ReducedData_ runs_4775-7039_HDF5	all COMBINED quantities; file name: **COMBINED_ReducedData_ runs_4775-7039_HDF5.zip** run range 4775-7039; 15,635,550 COMBINED events; no data arrays; no cuts applied,	1.0 GB
COMBINED_SmallDataSample_ nA_runs_4775-7039_HDF5	Data sample with every 40th event of the whole data set file name: **COMBINED_SmallDataSample_ nA_runs_4775-7039_HDF5.zip** **390,888 events equally distributed;** runs range 4775-7039; all detector components; all quantities available; no data arrays; no cuts applied;	27 MB
COMBINED_SmallDataSample_ wA_runs_4775-7039__HDF5	Data sample with every 40th event of the whole data set file name: **COMBINED_SmallDataSample_ wA_runs_4775-7039_HDF5.zip** **390,888 events equally distributed;** runs range 4775-7039; all detector components; all quantities available; including data arrays; no cuts applied;	647 MB
COMBINED_HighEnergyData_ runs_4775-7039_HDF5	Data sample with all events > 15.7 [$\log_{10}$ eV] file name: **COMBINED_HighEnergyData_ runs_4775-7039_HDF5.zip** all quantities; run range 4775-7039; 1,738,231 events; no data arrays; Energy cut 15.7 – 19.0[$\log_{10}$ eV]	131 MB

HDF5 Preselection		
Preselection Set Name	**Description**	**Size**
COMBINED_LOPES_nA _runs_5534-6821_HDF5	Data sample with LOPES radio events file name: **COMBINED_LOPES_nA_ runs_5534-6821_HDF5.zip** run range 5534-6821; 1430 LOPES events; no data arrays; no cuts applied,	304 kB

11.2 GET PRESELECTIONS

From the 'Data Shops' – 'Data Preselections' page registered users can download data sets directly just by clicking the respective download button (see fig 11.2.1). 'details' holds some detailed information on the respective Data Preselection.

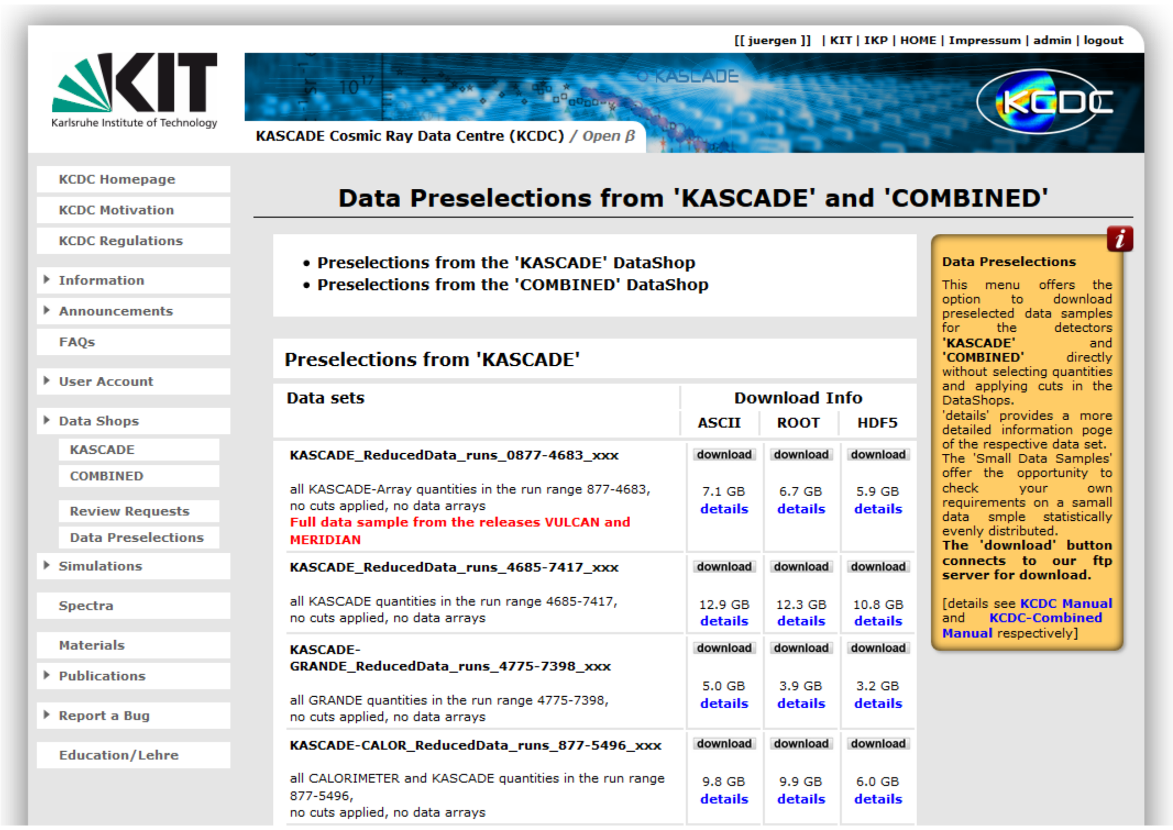


Fig. 11.2.1. *'Data Preselection' for direct download*

12 DATA FORMATS

12.1 ASCII

ASCII is a plain text data format. The KCDC data sets released with WOLF359 and VULCAN have only been transferred in ASCII data format. Due to a rapidly increasing number of parameters and meta information we changed to ***HDF5*** and ***ROOT*** file format respectively for coming releases. However, ASCII will be provided too but only for non-array quantities. If an array quantity like '*Muon Energy Deposit'* or '*Arrival Time'* is selected the ASCII format button will no longer be available.

For **ASCII** format up to six files are transmitted, depending on the detector components selected.

infos.txt	holds information on your requests, like the quantities selected and the cuts applied
combined.txt	data sets of the COMBINED quantities
lopes.txt	data sets of the LOPES quantities
general.txt	general event information
row_mapping.txt	event table, 'active/inactive' information on detector components
EULA.pdf	End User Licence Agreement

As it is possible that one or more detector components are missing in the respective event (due to for example repair etc.), the file **'row_mapping.txt'** is provided the user. It contains a row number for each component and is set to '-1' if the component was missing.

Helps on how to handle the row_mapping information and software examples can be downloaded from https://kcdc.iap.kit.edu/materials/ .

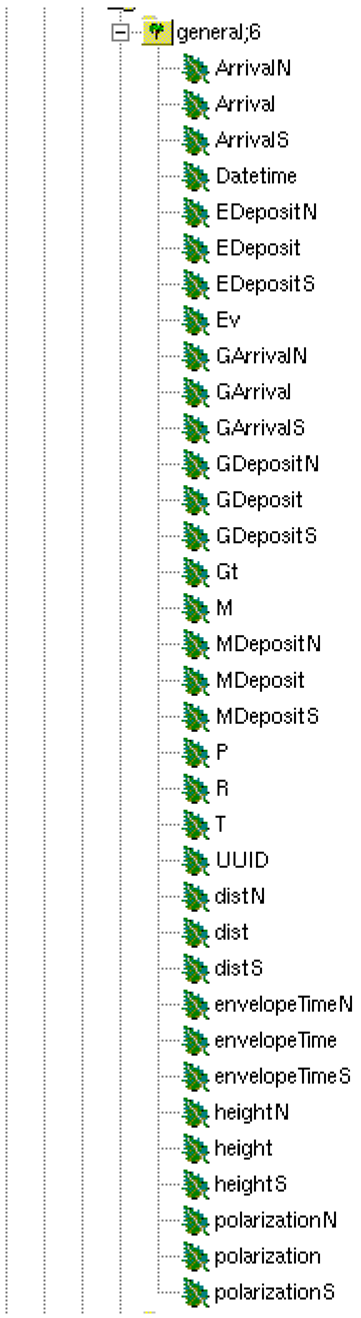
12.2 ROOT

ROOT is an object-oriented framework developed by CERN aimed at solving the data analysis challenges of high-energy physics.

For **ROOT** format only three files are transmitted

infos.txt	holds information on your requests, like the quantities selected and the cuts applied
events.root	root data sets for all selected quantities including 'row_map'
EULA.pdf	End User Licence Agreement

The root file contains one tree for each detector component and a tree to map the entries for the selected detector components for each event (see fig. 12.2.1.).



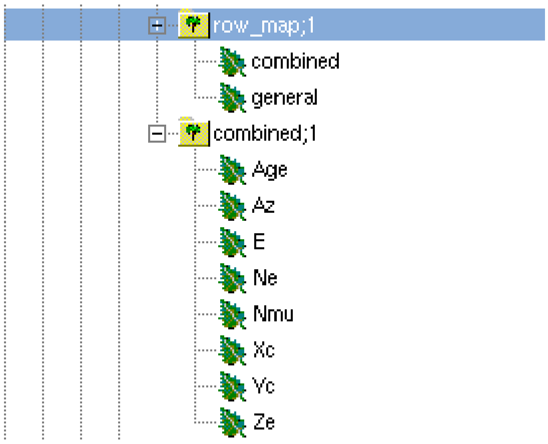


Fig. 12.2.1. *ROOT –trees example*

12.3 HDF5

Hierarchical Data Format (**HDF**) is a file format designed to store and organize large amounts of numerical data objects and a wide variety of metadata. HDF is a unique technology suite that makes possible the management of extremely large and complex data collections with no limit on the number or size of data objects. HDF is freely available distribution supported by many commercial and non-commercial software platforms, including Java, C, C++, Fortran 90 and Python. HDF provides a rich set of integrated performance features that allow for access time and storage space optimizations.

For **HDF5** format only three files are transmitted

infos.txt	holds information on your requests, like the quantities selected and the cuts applied
events.h5	hdf5 data sets for all selected quantities including ‘row_map’
EULA.pdf	End User Licence Agreement

The h5 file will contain one table for each detector component and a table to map the entries for the selected detector components for each event (see fig. 12.3.1.).

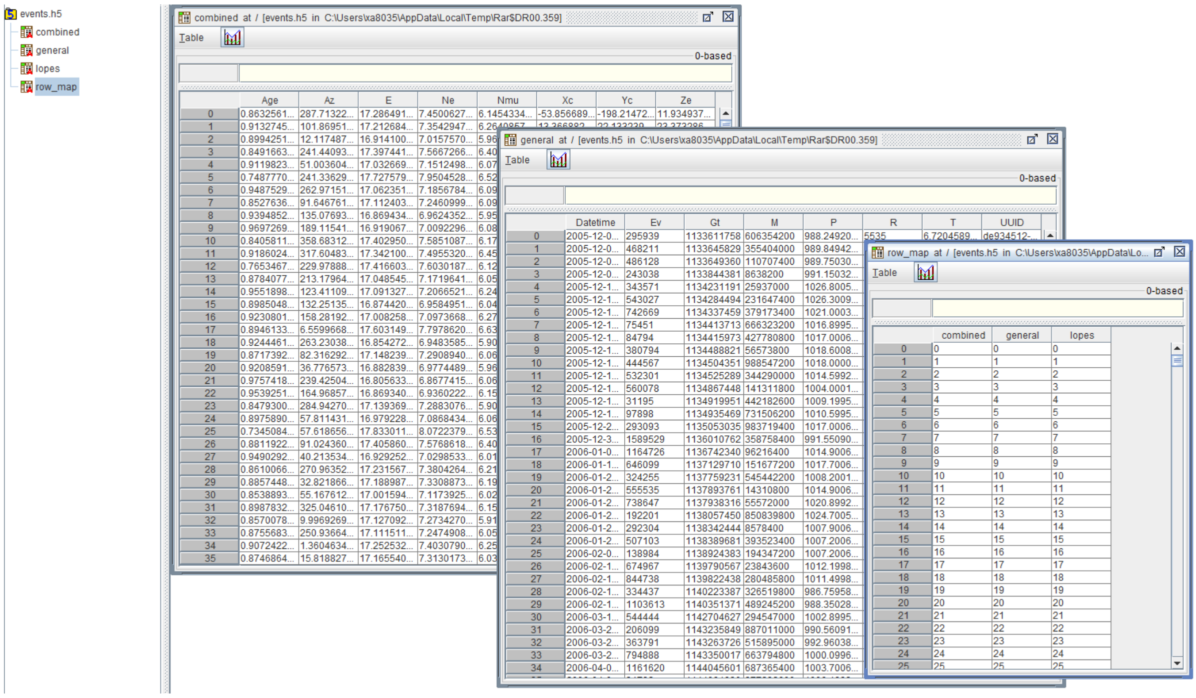


Fig. 12.3.1. *HDF5 –tree & data tables example*

KCDC provides the **HDF5** data format from the release MERIDIAN.

12.4 General Data Handling

The **row_mapping** information always provided with the data sets can be used to deselect time periods where a detector component was missing. In the present status this applies to the *'LOPES'* component. A deselected detector component is set to '-1' in the row_mapping file as shown in the example of fig 12.4.1 where the calorimeter was not active for some time. The event counter for this component was not increased.

```
combined general lopes
0          0        -1
1          1        -1
:
5853930  5853930  -1
5853931  5853931  401
:
15635548  15635548  -1
15635549  15635549  -1
```

Fig. 12.4.1. *Example of 'row_mapping.txt'*

If the order of events is important for the analysis (for example if you want to estimate the effective running time of the experiment by plotting the time difference between two subsequent events) you have to sort the data of the ASCII data file. As the run number [R] and the event number within one run [Ev] are both in increasing orders in time, a combination of those two quantities, which are for various reasons always shipped with the data, gives a correct sequence of the data sets. If the Global Time [GT] is selected it can be used in the same way to sort the data sample.

12.5 Problems while handling the Data Files

12.5.1 Warning when opening ROOT files

The root files are created using the 'ROOT 6' version. If you open the *events.root* file with a different version you might get some warnings as outlined below which can be ignored.

```
root [1] Warning in <TStreamerInfo::BuildCheck>:
  The StreamerInfo of class TTree read from file events.root
  has the same version (=19) as the active class but a different checksum.
  You should update the version to ClassDef(TTree,20).
  Do not try to write objects with the current class definition,
  the files will not be readable.

Warning in <TStreamerInfo::CompareContent>: The following data member of
the on-file layout version 19 of class 'TTree' differs from
the in-memory layout version 19:
  double fWeight; //
 :
 :
```

12.5.2 32-bit LINUX Systems

As the files transmitted can be rather large, we strongly recommend using a 64-bit system. There is p.e. a 2GB file-size limit in LINUX. This limit is deeply embedded in the versions of Linux for 32-bit CPUs so there is no workaround for this situation.

13 Data Set History

The data set history for all KCDC releases up to now can be found in detail in the "KCDC User Manual". This chapter holds information on the data sets (Quantities) published in the new release 'PENTARUS' and the Combined Data Analysis.

13.1 Data Sets for PENTARUS

The data sets for the KASCADE-Grande Combined Data Analysis published with KCDC release PENTARUS were recorded between 8.3.2004 and 4.11.2010, thus covering only a part of the whole measuring period of KASCADE and KASCADE-Grande. The data were recorded with the KASCADE and the Grande Array detectors. The events were processed with the KASCADE reconstruction program KRETA, Version V1.19/09 (Library compiled 20160216). The event selection is based on the requirements listed below, invoked by cuts adapted during data pre-processing using KRETA version V1.18/05.

In addition data recorded with the LOPES radio detection devices have been included as 'LOPES'. As the radio data were not part of the KASCADE data stream, the events have been merged offline by means of the transmitted time stamps. LOPES data were recorded in the time range 25.7.2005 (Run 5534) to 26.10.2009 (Run 6821). From this period, 1430 events survived all quality cuts and have been added to the KCDC DataShop.

In the table below the number of events published for the two detector components are listed.

Detector	Nr of Events
COMBINED	15,635,550
LOPES	1,430

13.1.1 COMBINED DATA SETS

The COMBINED Quantities published in PENTARUS are described in the table below.

	Quantity	Full Range
Energy	E	15.0 to 18.0 (log10) eV
Core Position X	Xc	-520.0 m to + 10.0 m
Core Position Y	Yc	-600.0 m to + 10.0 m
Zenith Angle	Ze	0.0° to 30.0°
Azimuth Angle	Az	0.0° to 360.0°
Number of Electrons	Ne	5.0 to 9.0 (log10)
Number of Muons	Nmu	3.0 to 8.0 (log10)
AGE	AGE	0.15 to 1.48

13.1.2 GENERAL DATA SETS

Date & Time	Datetime	8.3.2004– 4.11.2010
Global Time	Gt	1,078,737,917 – 1,288,855,193 s
Micro Time	Mt	0.0 to 999,999,999.0
Run Number	R	4775 to 7039
Event Number	Ev	1.0 to 4,100,000.0
Air Temperature	T	-20.0° to +50.0 °C
Air Pressure	P	960.0 to 1040.0 hPa
UUID	UUID	random number

13.1.3 LOPES Radio Antenna Data Sets

The complete ranges of the LOPES Quantities published in PENTARUS are described in the table below.

	Quantity	Full Range
E-Field Max	E-FieldMax	0 -50,000 V/m
Azimuth East-West	Azimuth EW	0 – 360°
Azimuth North-South	Azimuth NS	0 – 360°
Elevation East-West	Elevation EW	40 – 90°
Elevation North-South	Elevation NS	40 – 90°
CC Height East-West	CC Height EW	0 - 20 µV/m/MHz
CC Height North-South	CC Height NS	0 - 20 µV/m/MHz
X Height East-West	X Height EW	0 - 20 µV/m/MHz
X Height North-South	X Height NS	0 - 20 µV/m/MHz
Cone Angle East-West	ConeAngle EW	0 – 0.1 rad
Cone Angle North-South	ConeAngle NS	0 – 0.1 rad
NCC Beam Antenna East-West	NCCbeamAnt EW	0 - 30
NCC Beam Antenna North-South	NCCbeamAnt NS	0 - 30
Eta East-West	Eta EW	-0.04 – 0.1 1/m
Eta North-South	Eta NS	-0.04 – 0.1 1/m
Eps East-West	Eps EW	0 - 100 µV/m/MHz
Eps North-South	Eps NS	0 - 100 µV/m/MHz
Geomagnetic Angle	Geomag_Angle	0 – 120°
Reconstruction Index	Reconstruction	65 or 71 [A or G]

Envelope Time	LOPES envelope Time	-2500 – -1600 ns
Height	LOPES-Height	0 – 60 µV/m/MHz
Distance	LOPES-Distance	0 – 800 m
Polarization	LOPES-Polar	NS or EW or both

The parameter **LopesCompID** was introduced as an identifier for data sets, which contain LOPES events.

14 Reference List

14.1 KCDC

The KASCADE Cosmic-ray Data Centre KCDC: Granting Open Access to Astroparticle Physics Research Data

The European Physical Journal C (2018) →publication to be cited

A new release of the KASCADE Cosmic Ray Data Centre (KCDC)

35th International Cosmic Ray Conference (ICRC)

Bexco, Busan, Korea; 12. - 20.7.2017

The KASCADE Cosmic-ray Data Centre (KCDC)

34th International Cosmic Ray Conference (ICRC)

The Hague, Netherlands; 30.7. - 6.8.2015

The KASCADE Cosmic-ray Data Centre (KCDC)

24th European Cosmic Ray Symposium (ECRS)

Kiel, Germany; 1. - 5.9.2014

The KASCADE Cosmic ray Data Centre - providing open access to astroparticle physics research data

Helmholtz Open Access Webinars on Research Data Webinar

15; 8. - 12.11.2013

KCDC - publishing research data from the KASCADE experiment

Helmholtz Open Access Workshop

DESY, Hamburg; 11.6.2013

14.2 KASCADE

The Cosmic-Ray Experiment – KASCADE

Nuclear Instruments and Methods; A513 (2003) p490-510

A Warm-liquid Calorimeter for Cosmic-ray Hadrons

Nuclear Instruments and Methods; A427 (1999) 528-542

14.3 KASCADE-GRANDE

The KASCADE-Grande experiment

Nuclear Instruments and Methods; A620 (2009) p202-216

14.4 LOPES

The LOPES radio antennas

Nucl.Instr. and Meth.A604 (2009) 1-8

Nucl.Instr. and Meth.A969 (2012) 100-109

14.5 WEB –LINKS

For nore information on KASCDE/KASCADE see:

https://web.iap.kit.edu/KASCADE/

For nore information on KCDC see:

https://kcdc.iap.kit.edu/

14.6 GENERAL –LINKS

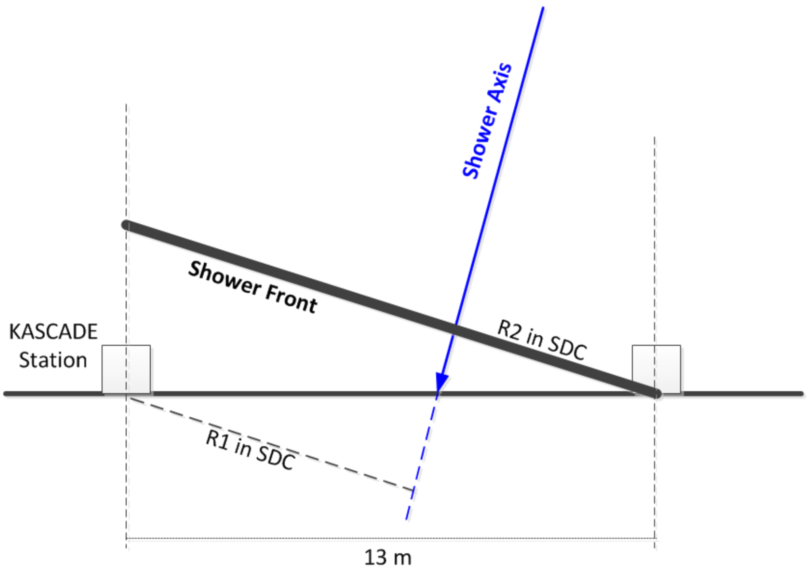
Berlin declaration

https://openaccess.mpg.de/Berlin-Declaration

15 GLOSSARY

CC-Beam	The CC-Beam (cross-correlation beam) is the result of the interferometry combination of radio antennas. This is done by calculating the cross-correlation of all antenna pairs. So each signal of one antenna is multiplied by the signals of all other antennas. These values are then averaged. The square root is thus the value of the CC beam, keeping the sign as the sign of the CC beam. This indicates whether the original signals were coherent or not. The CC beam of a coherent signal is always positive, while incoherent noise gives a value close to zero, as contributions of different signs are averaged out. An anti-phase signal in the antenna pairs provides a negative value for the CC beam.
CORSIKA	**CORSIKA** (**CO**smic **R**ay **SI**mulations for **KA**scade) is a program package 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.
CRES	**CRES** (**C**osmic **R**ay **E**vent **S**imulation) is code package for the simulation of the signals / energy deposits in all detector components of KASCADE/KASCADE-Grande as response to an extensive air shower as simulated with **CORSIKA**.
KAOS	**KAOS** is the acronym for **K**arlsruhe **A**stroparticlephysics **O**pen data **S**oftware. It has been written in the context of the KASCADE Cosmic Ray Data Centre (**KCDC**), a web portal designed for the publication of scientific data recorded with the KASCADE experiment. **KAOS** is implemented using a plugin-based design with a focus on easy extensibility and modifiability in order to work also outside the context of KCDC.

KRETA	**KRETA** (**K**ascade **R**econstruction of **Ext**ensive **A**ir showers) is the main data analysis engine of the KASCADE/KASCADE-Grande Experiment. KRETA is written in Fortran77 and makes extensive use of the CERN library and its various software packages.
MIP	**Minimum ionizing particles (MIPS)** are charged particles, which embody the minimum ionizing losses in substances. This situation occurs when the kinetic energy of particles is at least twice larger than their rest mass. For example, electrons (or protons) can be considered as minimum ionizing particles when their kinetic energy is greater than 1 MeV (or GeV 2). Since the ionization losses of these particles are only weakly dependent on their momentum, it is generally accepted that minimum ionizing particles produce an even distribution of free charge carriers along their paths. Muons for example suffer an energy loss of roughly 1.5 MeV/cm when passing through a plastic scintillator.
P-Beam	The P-beam (power beam) is calculated as the root of the average power of all antennas, which is always positive. However, it cannot be determined whether a signal is coherent or not.
Quantity	The KASCADE variables published in the KCDC web portal are called quantities
SDC	**S**hower **D**isc **C**oordinates. The sketch below illustrates how the radii R1 and R2 are calculated in SDC.



ZEBRA **ZEBRA** is a memory management system and part of the CERN library. ZEBRA allows a dynamic creation of data structures at execution time as well as the manipulation of those structures.

16 APPENDIX

16.1 APPENDIX A

Correlation between station ID as given in the data arrays and the x- and y-positions in KASCADE coordinates. The positions are given in [m]. The column 'Detect' shows the detectors installed (number of e/γ and μ detectors). The red numbers indicate that the station is dislocated from the regular grid. Four stations in the centre of the KASCADE array are missing, their positions are blocked by the central calorimeter. The scheme of the nomenclature is illustrated in fig. A.1.

St-ID	X- Y-Position [m]	Detect	St-ID	X- Y-Position [m]	Detect	St-ID	X- Y-Position [m]	Detect
1	-97.5 / -97.5	2 e/γ & 4μ	85	-19.5 / -45.5	4 e/γ	169	6.5 / 32.5	4 e/γ
2	-84.5 / -97.5	2 e/γ & 4μ	86	-6.5 / -45.5	4 e/γ	170	19.5 / 32.5	4 e/γ
3	-84.5 / -84.5	2 e/γ & 4μ	87	-6.5 / -32.5	4 e/γ	171	19.5 / 45.5	4 e/γ
4	-97.5 / -84.5	2 e/γ & 4μ	88	-19.5 / -32.5	4 e/γ	172	6.5 / 45.5	4 e/γ
5	-71.5 / -97.5	2 e/γ & 4μ	89	-19.5 / -19.5	4 e/γ	173	58.5 / 6.5	2 e/γ & 4μ
6	-58.5 / -97.5	2 e/γ & 4μ	90	-6.3 / -18.5	4 e/γ	174	71.5 / 6.5	2 e/γ & 4μ
7	-58.5 / -84.5	2 e/γ & 4μ	91	-19.5 / -6.5	4 e/γ	175	71.5 / 19.5	2 e/γ & 4μ
8	-71.5 / -84.5	2 e/γ & 4μ	92	-45.5 / -19.5	4 e/γ	176	58.5 / 19.5	2 e/γ & 4μ
9	-71.5 / -71.5	2 e/γ & 4μ	93	-32.5 / -19.5	4 e/γ	177	84.5 / 6.5	2 e/γ & 4μ
10	-58.5 / -71.5	2 e/γ & 4μ	94	-32.5 / -6.5	4 e/γ	178	97.5 / 6.5	2 e/γ & 4μ
11	-58.5 / -58.5	2 e/γ & 4μ	95	-45.5 / -6.5	4 e/γ	179	97.5 / 19.5	2 e/γ & 4μ
12	-71.5 / -58.5	2 e/γ & 4μ	96	6.5 / -45.5	4 e/γ	180	84.5 / 19.5	2 e/γ & 4μ
13	-97.5 / -71.5	2 e/γ & 4μ	97	19.5 / -45.5	4 e/γ	181	84.5 / 32.5	2 e/γ & 4μ
14	-84.5 / -71.5	2 e/γ & 4μ	98	19.5 / -32.5	4 e/γ	182	97.5 / 32.5	2 e/γ & 4μ
15	-84.5 / -58.5	2 e/γ & 4μ	99	6.5 / -32.5	4 e/γ	183	97.5 / 45.5	2 e/γ & 4μ
16	-97.5 / -58.5	2 e/γ & 4μ	100	32.5 / -45.5	4 e/γ	184	84.5 / 45.5	2 e/γ & 4μ
17	-45.5 / -97.5	2 e/γ & 4μ	101	45.5 / -45.5	4 e/γ	185	58.5 / 32.5	2 e/γ & 4μ
18	-32.5 / -97.5	2 e/γ & 4μ	102	45.5 / -32.5	4 e/γ	186	71.5 / 32.5	2 e/γ & 4μ
19	-32.5 / -84.5	2 e/γ & 4μ	103	32.5 / -32.5	4 e/γ	187	71.5 / 45.5	2 e/γ & 4μ
20	-45.5 / -84.5	2 e/γ & 4μ	104	32.5 / -19.5	4 e/γ	188	58.5 / 45.5	2 e/γ & 4μ
21	-19.5 / -97.5	2 e/γ & 4μ	105	45.5 / -19.5	4 e/γ	189	-97.5 / 58.5	2 e/γ & 4μ
22	-6.5 / -97.5	2 e/γ & 4μ	106	45.5 / -6.5	4 e/γ	190	-84.5 / 58.5	2 e/γ & 4μ
23	-6.5 / -84.5	2 e/γ & 4μ	107	32.5 / -6.5	4 e/γ	191	-84.5 / 71.5	2 e/γ & 4μ
24	-19.5 / -84.5	2 e/γ & 4μ	108	7.5 / -19.5	4 e/γ	192	-97.5 / 71.5	2 e/γ & 4μ
25	-19.5 / -71.5	2 e/γ & 4μ	109	19.5 / -19.5	4 e/γ	193	-71.5 / 58.5	2 e/γ & 4μ
26	-6.5 / -71.5	2 e/γ & 4μ	110	19.5 / -6.5	4 e/γ	194	-58.5 / 58.5	2 e/γ & 4μ

St-ID	X- Y-Position [m]	Detect	St-ID	X- Y-Position [m]	Detect	St-ID	X- Y-Position [m]	Detect
27	-6.5 / -58.5	2 e/γ & 4μ	111	58.5 / -45.5	2 e/γ & 4μ	195	-58.5 / 71.5	2 e/γ & 4μ
28	-19.5 / -58.5	2 e/γ & 4μ	112	71.5 / -45.5	2 e/γ & 4μ	196	-71.5 / 71.5	2 e/γ & 4μ
29	-45.5 / -71.5	2 e/γ & 4μ	113	71.5 / -32.5	2 e/γ & 4μ	197	-71.5 / 84.5	2 e/γ & 4μ
30	-32.5 / -71.5	2 e/γ & 4μ	114	58.5 / -32.5	2 e/γ & 4μ	198	-58.5 / 84.5	2 e/γ & 4μ
31	-32.5 / -58.5	2 e/γ & 4μ	115	84.5 / -45.5	2 e/γ & 4μ	199	-58.5 / 97.5	2 e/γ & 4μ
32	-45.5 / -58.5	2 e/γ & 4μ	116	97.5 / -45.5	2 e/γ & 4μ	200	-71.5 / 97.5	2 e/γ & 4μ
33	6.5 / -97.5	2 e/γ & 4μ	117	97.5 / -32.5	2 e/γ & 4μ	201	-97.5 / 84.5	2 e/γ & 4μ
34	19.5 / -97.5	2 e/γ & 4μ	118	84.5 / -32.5	2 e/γ & 4μ	202	-84.5 / 84.5	2 e/γ & 4μ
35	19.5 / -84.5	2 e/γ & 4μ	119	84.5 / -19.5	2 e/γ & 4μ	203	-84.5 /97.5	2 e/γ & 4μ
36	6.5 / -84.5	2 e/γ & 4μ	120	97.5 / -19.5	2 e/γ & 4μ	204	-97.5 /97.5	2 e/γ & 4μ
37	32.5 / -97.5	2 e/γ & 4μ	121	97.5 / -6.5	2 e/γ & 4μ	205	-45.5 / 58.5	2 e/γ & 4μ
38	45.5 / -97.5	2 e/γ & 4μ	122	84.5 / -6.5	2 e/γ & 4μ	206	-32.5 / 58.5	2 e/γ & 4μ
39	45.5 / -84.5	2 e/γ & 4μ	123	58.5 / -19.5	2 e/γ & 4μ	207	-32.5 / 71.5	2 e/γ & 4μ
40	32.5 / -84.5	2 e/γ & 4μ	124	71.5 / -19.5	2 e/γ & 4μ	208	-45.5 / 71.5	2 e/γ & 4μ
41	32.5 / -71.5	2 e/γ & 4μ	125	71.5 / -6.5	2 e/γ & 4μ	209	-19.5 / 58.5	2 e/γ & 4μ
42	45.5 / -71.5	2 e/γ & 4μ	126	58.5 / -6.5	2 e/γ & 4μ	210	-6.5 / 58.5	2 e/γ & 4μ
43	45.5 / -58.5	2 e/γ & 4μ	127	-97.5 / 6.5	2 e/γ & 4μ	211	-6.5 / 71.5	2 e/γ & 4μ
44	32.5 / -58.5	2 e/γ & 4μ	128	-84.5 / 6.5	2 e/γ & 4μ	212	-19.5 / 71.5	2 e/γ & 4μ
45	6.5 / -71.5	2 e/γ & 4μ	129	-84.5 / 19.5	2 e/γ & 4μ	213	-19.5 / 84.5	2 e/γ & 4μ
46	19.5 / -71.5	2 e/γ & 4μ	130	-97.5 / 19.5	2 e/γ & 4μ	214	-6.5 / 84.5	2 e/γ & 4μ
47	19.5 / -58.5	2 e/γ & 4μ	131	-71.5 / 6.5	2 e/γ & 4μ	215	-6.5 / 97.5	2 e/γ & 4μ
48	6.5 / -58.5	2 e/γ & 4μ	132	-58.5 / 6.5	2 e/γ & 4μ	216	-19.5 / 97.5	2 e/γ & 4μ
49	58.5 / -97.5	2 e/γ & 4μ	133	-58.5 / 19.5	2 e/γ & 4μ	217	-45.5 / 84.5	2 e/γ & 4μ
50	71.5 / -97.5	2 e/γ & 4μ	134	-71.5 / 19.5	2 e/γ & 4μ	218	-32.5 / 84.5	2 e/γ & 4μ
51	71.5 / -84.5	2 e/γ & 4μ	135	-71.5 / 32.5	2 e/γ & 4μ	219	-32.5 / 97.5	2 e/γ & 4μ
52	58.5 / -84.5	2 e/γ & 4μ	136	-58.5 / 32.5	2 e/γ & 4μ	220	-45.5 / 97.5	2 e/γ & 4μ
53	84.5 / -97.5	2 e/γ & 4μ	137	-58.5 / 45.5	2 e/γ & 4μ	221	6.5 / 58.5	2 e/γ & 4μ
54	97.5 / -97.5	2 e/γ & 4μ	138	-71.5 / 45.5	2 e/γ & 4μ	222	19.5 / 58.5	2 e/γ & 4μ
55	97.5 / -84.5	2 e/γ & 4μ	139	-97.5 / 32.5	2 e/γ & 4μ	223	19.5 / 71.5	2 e/γ & 4μ
56	84.5 / -84.5	2 e/γ & 4μ	140	-84.5 / 32.5	2 e/γ & 4μ	224	6.5 / 71.5	2 e/γ & 4μ
57	84.5 / -71.5	2 e/γ & 4μ	141	-84.5 / 45.5	2 e/γ & 4μ	225	32.5 / 58.5	2 e/γ & 4μ
58	97.5 / -71.5	2 e/γ & 4μ	142	-97.5 / 45.5	2 e/γ & 4μ	226	45.5 / 58.5	2 e/γ & 4μ
59	97.5 / -58.5	2 e/γ & 4μ	143	-45.5 / 6.5	4 e/γ	227	45.5 / 71.5	2 e/γ & 4μ
60	84.5 / -58.5	2 e/γ & 4μ	144	-32.5 / 6.5	4 e/γ	228	32.5 / 71.5	2 e/γ & 4μ
61	58.5 / -71.5	2 e/γ & 4μ	145	-32.5 / 19.5	4 e/γ	229	32.5 / 84.5	2 e/γ & 4μ
62	71.5 / -71.5	2 e/γ & 4μ	146	-45.5 / 19.5	4 e/γ	230	45.5 / 84.5	2 e/γ & 4μ
63	71.5 / -58.5	2 e/γ & 4μ	147	-19.5 / 6.5	4 e/γ	231	45.5 / 97.5	2 e/γ & 4μ
64	58.5 / -58.5	2 e/γ & 4μ	148	-6.3 / 24.5	4 e/γ	232	32.5 / 97.5	2 e/γ & 4μ
65	-97.5 / -45.5	2 e/γ & 4μ	149	-19.5 / 19.5	4 e/γ	233	6.5 / 84.5	2 e/γ & 4μ

St-ID	X- Y-Position [m]	Detect	St-ID	X- Y-Position [m]	Detect	St-ID	X- Y-Position [m]	Detect
66	-84.5 / -45.5	2 e/γ & 4μ	150	-19.5 / 32.5	4 e/γ	234	19.5 / 84.5	2 e/γ & 4μ
67	-84.5 / -32.5	2 e/γ & 4μ	151	-6.5 / 32.5	4 e/γ	235	19.5 / 97.5	2 e/γ & 4μ
68	-97.5 / -32.5	2 e/v & 4μ	152	-6.5 / 45.5	4 e/γ	236	6.5 / 97.5	2 e/γ & 4μ
69	-71.5 / -45.5	2 e/γ & 4μ	153	-19.5 / 45.5	4 e/γ	237	58.5 / 58.5	2 e/γ & 4μ
70	-58.5 / -45.5	2 e/v & 4μ	154	-45.5 / 32.5	4 e/γ	238	71.5 / 58.5	2 e/γ & 4μ
71	-58.5 / -32.5	2 e/γ & 4μ	155	-32.5 / 32.5	4 e/γ	239	71.5 / 71.5	2 e/γ & 4μ
72	-71.5 / -32.5	2 e/γ & 4μ	156	-32.5 / 45.5	4 e/γ	240	58.5 / 71.5	2 e/γ & 4μ
73	-71.5 / -19.5	2 e/γ & 4μ	157	-45.5 / 45.5	4 e/γ	241	84.5 / 58.5	2 e/γ & 4μ
74	-58.5 / -19.5	2 e/γ & 4μ	158	19.5 / 6.5	4 e/γ	242	97.5 / 58.5	2 e/γ & 4μ
75	-58.5 / -6.5	2 e/γ & 4μ	159	19.5 / 19.5	4 e/γ	243	97.5 / 71.5	2 e/γ & 4μ
76	-71.5 / -6.5	2 e/γ & 4μ	160	10.2 / 24.1	4 e/γ	244	84.5 / 71.5	2 e/γ & 4μ
77	-97.5 / -19.5	2 e/v & 4μ	161	32.5 / 6.5	4 e/γ	245	84.5 / 84.5	2 e/γ & 4μ
78	-84.5 / -19.5	2 e/γ & 4μ	162	45.5 / 6.5	4 e/γ	246	97.5 / 84.5	2 e/γ & 4μ
79	-84.5 / -6.5	2 e/γ & 4μ	163	45.5 / 19.5	4 e/γ	247	97.5 / 97.5	2 e/γ & 4μ
80	-97.5 / -6.5	2 e/γ & 4μ	164	32.5 / 19.5	4 e/γ	248	84.5 / 97.5	2 e/γ & 4μ
81	-45.5 / -45.5	4 e/γ	165	32.5 / 32.5	4 e/γ	249	58.5 / 84.5	2 e/γ & 4μ
82	-32.5 / -45.5	4 e/γ	166	45.5 / 32.5	4 e/γ	250	71.5 / 84.5	2 e/γ & 4μ
83	-32.5 / -32.5	4 e/γ	167	45.5 / 45.5	4 e/γ	251	71.5 /97.5	2 e/γ & 4μ
84	-45.5 / -32.5	4 e/γ	168	32.5 / 45.5	4 e/γ	252	58.5 /97.5	2 e/γ & 4μ

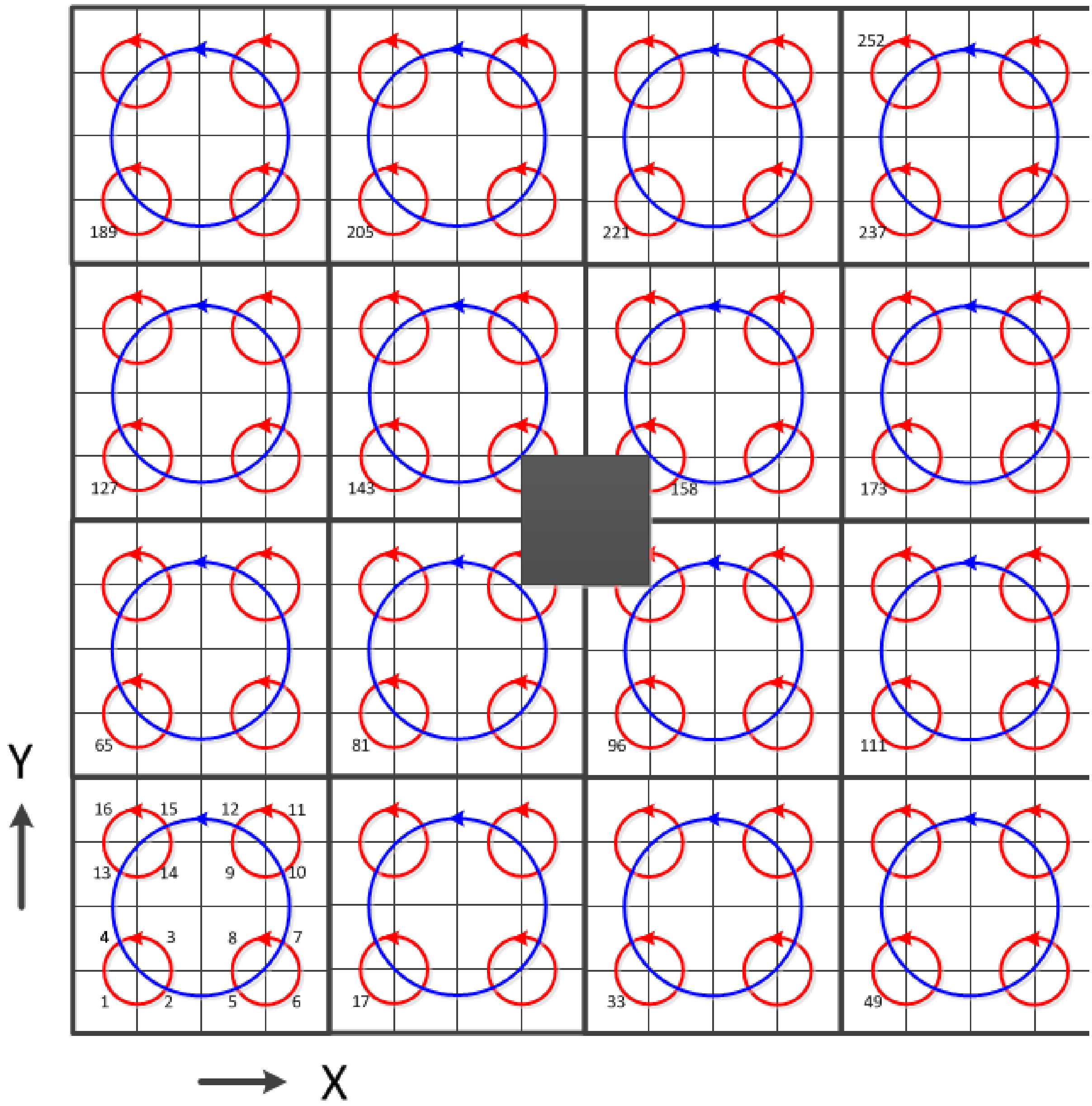


Fig. A.1 *The scheme of the counting of the array station IDs (1 ... 252)* python-code to calculate x- and y-positions from the station IDs

```
def get_station_locs():
    dstcl = 5200.                              // width of array cluster
    dstqa = 2600.                              // width of one sub-cluster
    dstas = 1300.                              // distance between stations
    sddy = [-1., -1., 1., 1.]                  // count matrix X
    sddx = [-1., 1., 1., -1.]                  // count matrix Y
    iasn = 0
    real_iasn = 0
    stations = {}

    for icl in range(1, 17):
        ycl = (float(floor((icl-1)/4))-1.5)*dstcl
        xcl = (float(fmod(icl-1, 4))-1.5)*dstcl

        for j in range(0,4):
            yqa = ycl + 0.5 * dstqa*sddy[j]
            xqa = xcl + 0.5 * dstqa*sddx[j]
            for k in range(0,4):
                yas = yqa + 0.5 * dstas*sddy[k]
                xas = xqa + 0.5 * dstas*sddx[k]
                iasn += 1

                if yas < -dstas or yas > dstas or xas < -dstas or xas > dstas:
                    real_iasn += 1
                    iccdd = icl * 100 + fmod(iasn-1, 16) + 1

#   stations dislocated from the regular grid
                    if iccdd == 610:                # ID 90
                        xas += 23.0
                        yas += 100.
                    elif iccdd == 713:              # ID 108
                        xas += 100.
                    elif iccdd == 1007:             # ID 148
                        xas += 20.
                        yas += 495.9
                    elif iccdd == 1104:             # ID 160
                        xas += 366.5
                        yas += 461.0

                    stations[str(real_iasn)] = [xas/100., yas/100.]
    return stations
```

16.2 Appendix B

Correlation between the GRANDE station ID as given in the Grande data arrays and the x- and y-positions in KASCADE coordinates. The positions are given in [m] in reference to the KASCADE array centre. The red numbers indicate that the station has been moved during the lifetime of Grande.

Date of validity for the positions given in the table below is 20.12.2003 – 5.11.2012

St-ID	X- Y- Z-Position [m]	St-ID	X- Y- Z-Position [m]	St-ID	X- Y- Z-Position [m]
1	-0.14 / 65.33 / 2.47	14	-260.09 / -136.2 / 1.52	27	-533.7 / -409.1 / 0.87
2	-131.3 / 70.87 / 2.05	15	-377.5 / -145.0 / 1.67	28	101.2 / -507.6 / 1.74
3	-257.0 / 101.7 / 1.96	16	-481.5 / -155.5 / 1.83	29	-24.72 / -507.6 / 1.90
4	-384,8 / 96.12 / 0.84	17	44.09 / -276.6 / 1.65	30	-196.5 / -504.1 / 1.81
5	-499.6 / 95.51 / 1.81	18	-95.83 / -276.0 / 1.29	31	-317.9 / -529.2 / 1.84
6	64.48 / -42.03 / 1.15	19	-195.4 / -272.6 / 1.63	32	-443.3 / -525.9 / 1.95
7	-64.99 / -41.42 / 1.11	20	-319.8 / -267.6 / 1.92	33	-566.5 / -526.4 / 0.63
8	-211.2 / -40.54 / 1.47	21	-481.5 / -234.9 / 1.59	34	-111.9 / -654.9 / 1.90
9	-329.0 / -49.29 / 1.86	22	-608.3 / -281.8 / 0.94	35	-275.0 / -645.4 / 1.71
10	-426.1 / -7.66 / 1.46	23	24.79 / -391.3 / 1.32	36	-389.1 / -653.3 / 1.71
11	-569.8 / 46.42 / 1.90	24	-112.9 / -383.6 / 1.66	37	-517.9 / -620.8 / 1.96
12	24.21 / -156.6 / 1.31	25	-249.8 / -392.0 / 1.48		
13	-140.1 / -143.8 / 1.53	26	-386.5 / -382.1 / 1.84		

16.2.1 Modifications of the GRANDE Station positions

Stations 8 and 30 had to be moved from their original locations by several meters. Their positions and the matching *dates of validity* are outlined in the table below.

St-ID	X- Y- Z-Position [m]	valid from	valid until
8	-211.2 / -40.54 / 1.47	20.12.2003 00:00	23.09.2005 12:00
8	-224.4 / -33.68 / 2.03	23.09.2005 12:00	5.11.2012 23:59
30	-196.5 / -504.1 / 1.81	20.12.2003 00:00	11.05.2011 00:00
30	-193.9 / -525.0 / 1.81	11.05.2011 00:00	5.11.2012 23:59

16.3 Appendix C

Correlation between the LOPES antenna ID as used in LOPES and the x- and y-positions in LOPES- (C.1) and KASCADE-coordinates (C.2).

16.3.1 C.1 - LOPES Coordinates

Ant-ID	X-Position [m]	Y-Position [m]	Z-Position [m]	Polarization
1	79.73	-45.60	1.12	NS
2	111.59	-63.98	1.05	EW
3	36.31	-84.52	1.19	NS
4	54.80	-52.61	1.13	EW
5	22.72	-34.17	1.07	EW
6	22.72	-34,17	1.07	NS
7	2.18	41.15	1.21	NS
8	34.48	22.88	1.16	EW
9	72.72	-20.68	1.06	EW
10	91.02	11.28	0.96	NS
11	-64.10	-111.95	1.27	NS
12	-45.77	-79.76	1.30	EW
13	-84.46	-36.48	1.35	EW
14	-52.31	-54.49	1.25	NS
15	-91.37	-11.36	1.38	NS
16	-72.91	20.41	1.47	EW
17	-111.81	63.48	1.53	EW
18	-79.92	45.56	1.53	NS
19	-34.37	-22.83	1.28	EW
20	-34.37	-22.83	1.28	NS
21	-13.70	-97.84	1.53	EW
22	4.51	-65.93	1.50	EW
23	-41.18	2.16	1.32	NS
24	-22.79	33.43	1.21	EW
25	-61.46	77.65	1.43	EW
26	-29.63	59.18	1.28	NS
27	-7.55	-127.63	1.39	NS
28	-7.55	-127.63	1.39	EW
29	-13.70	-97.84	1.53	NS
30	4.51	-65.93	1.50	NS

In LOPES coordinates the positions of the antennas are given in [m] with reference to the KASCADE array centre. But unlike the KASCADE coordinate system, the X-axis points north, the Y-axis points east and the system rotates anti-clockwise. The red numbers indicate that the antenna has been moved during the lifetime of LOPES as outlined in the table below.

16.3.2 C.2 - KASCADE COORDINATES

Ant-ID	X-Position [m]	Y-Position [m]	Z-Position [m]	Polarization
1	-62.60	56.24	1.12	NS
2	-91.08	90.83	1.05	EW
3	-91.09	12.80	1.19	NS
4	-65.17	39.04	1.13	EW
5	-38.94	12.93	1.07	EW
6	-38.94	12.93	1.07	EW
7	39.12	12.93	1.21	NS
8	13.00	39.28	1.16	EW
9	-39.08	64.72	1.06	EW
10	-13.06	90.78	0.96	NS
11	-91.15	-91.29	1.27	NS
12	-64.91	-65.13	1.30	EW
13	-12.98	-91.08	1.35	EW
14	-38.81	-64.80	1.25	NS
15	13.07	-91.14	1.38	NS
16	38.86	-64.97	1.47	EW
17	90.65	-91.17	1.53	EW
18	64.98	-65.12	1.53	NS
19	-12.98	-39.16	1.28	EW
20	-12.98	-39.16	1.28	EW
21	-90.80	-38.95	1.53	EW
22	-64.79	-12.99	1.50	EW
23	12.91	-39.16	1.32	NS
24	38.25	-13.19	1.21	EW
25	91.08	-38.87	1.43	EW
26	64.89	-13.02	1.28	NS
27	-121.14	-40.85	1.39	NS
28	-121.14	-40.85	1.39	NS
29	-90.80	-38.95	1.53	EW
30	-64.79	-12.99	1.50	EW

In KASCADE coordinates the positions of the antennas are as well given in [m] with reference to the KASCADE array centre, but in this coordinate system, the X-axis points east, the Y-axis points north and the system rotates clockwise. The red numbers indicate that the antenna has been moved during the lifetime of LOPES as outlined in the table below.

16.3.3 C.3 - Modifications of the LOPES antenna positions

In the beginning of the measurements called 'LOPES-30' (see fig. C.3.1) all antennas were aligned in East-Western direction. These alignments have been changed for several antennas but their positions remained unchanged.

Ant-ID	action	valid from	valid until
27	alignment moved to NS	10.8.2006 12:00	end of measurement
29	alignment moved to NS	10.8.2006 12:00	end of measurement
30	alignment moved to NS	10.8.2006 12:00	end of measurement
3	alignment moved to NS	8.12.2006 10:44	end of measurement
6	alignment moved to NS	8.12.2006 10:44	end of measurement
7	alignment moved to NS	8.12.2006 10:44	end of measurement
10	alignment moved to NS	8.12.2006 10:44	end of measurement
11	alignment moved to NS	8.12.2006 10:44	end of measurement
14	alignment moved to NS	8.12.2006 10:44	end of measurement
15	alignment moved to NS	8.12.2006 10:44	end of measurement
18	alignment moved to NS	8.12.2006 10:44	end of measurement
20	alignment moved to NS	8.12.2006 10:44	end of measurement
23	alignment moved to NS	8.12.2006 10:44	end of measurement
26	alignment moved to NS	8.12.2006 10:44	end of measurement
27	alignment moved to NS	8.12.2006 10:44	end of measurement
29	alignment moved to NS	8.12.2006 10:44	end of measurement
30	alignment moved to NS	8.12.2006 10:44	end of measurement
1	alignment moved to NS	24.1.2007 13:15	end of measurement
19	interchanged with ant-20	17.1.2008 11:40	end of measurement
20	interchanged with ant-19	17.1.2008 11:40	end of measurement

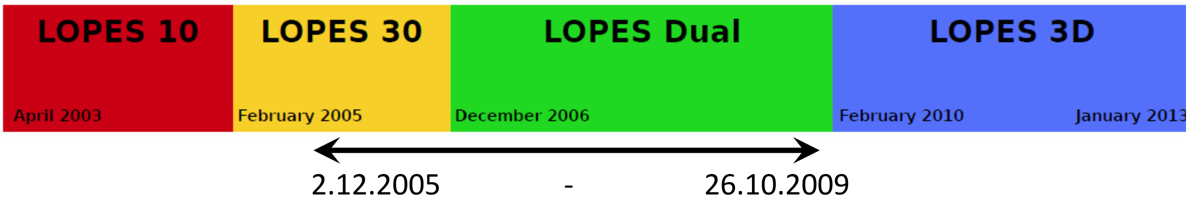


Fig.C.3.1 *Overview of the different LOPES setups and the time range where data are available in KCDC*

Before December 2005 no proper amplitude calibration is available and after October 2009 the reconfiguration to the Tripole setup started and due to the different antenna type no combined analysis was done.