



KCDC Simulation Manual - KASCADE, GRANDE and CALORIMETER Simulations

KCDC - the KASCADE Cosmic Ray Data Centre

Open Access Solution for the
KARlsruhe Shower Core and Array Detector (KASCADE)

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Internet:	kcdc.iap.kit.edu www.kit.edu
DOI:	https://doi.org/10.17616/R3TS4P
Version:	V.02.2
Last update:	2022-05-04

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1 INTRODUCTION

The **KCDC Simulation Manual** provides detailed explanation of data sets simulated for the KASCADE/KASCADE-Grande experiment and made publicly accessible with the KCDC Project Internet Application.

For information on simulations concerning other experiments published via the KCDC web portal, like 'COMBEND', please refer to the corresponding manuals.

The KCDC-team is quite aware of the fact that not all details concerning air shower simulation, detector simulation and the analysis of the data can be described in this manual. Details of the KASCADE/KASCADE-Grande detector layout and the analysis of the measured data are published in the 'KCDC-Manual' as well available. Thus we kindly ask the user to get the details from there.

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 the astroparticle physics experiment KASCADE are be made available via various so called 'DataShops' 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 that 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

1 Introduction

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 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. However, due to basic differences in the measurements of cosmic-ray induced air showers compared with astronomical data, KCDC provides the first conceptual design, how the data can be treated and processed so that they are reasonably usable outside the community of experts in the research field. Since 18.11.2013 the KCDC web portal is online and the amount of data has been extended in three major releases since then. With the release '**NABOO 2.0**' we offered as well simulation data from three major high-energy models, QGSjet, EPOS and SIBYLL with two to three different sub-models each.

The following chapter describes shortly the air shower simulation with CORSIKA, the KASCADE detector simulation using the cosmic ray event simulation code CRES (**Cosmic Ray Events Simulation**) and the reconstruction code KRETA (**KASCADE Reconstruction of Extensive Air showers**).

1.2 WHY SIMULATIONS

Analysing experimental data on Extensive Air Showers (EAS) requires a detailed theoretical modelling of the cascade, which develops when a high-energy primary particle enters the atmosphere. This can only be achieved by detailed Monte Carlo calculations taking into account all knowledge of high-energy strong and electromagnetic interactions.

2 SIMULATIONS

As the flux of primary cosmic ray particles in the energy range close to and above 1 PeV is very small, indirect measurements via the detection of extensive air showers induced by high energetic particles entering the atmosphere are feasible at present. Determination of spectra for individual elements or mass groups is limited by the large intrinsic fluctuations of EAS observables. Furthermore, any analysis of air shower data has to rely on EAS simulations and our limited knowledge of particle physics in the energy range of relevance. Since the primary energies of the showers are beyond the energy range of man-made accelerators and reactions relevant to shower development occur in the very forward direction not accessible in collider experiments, uncertainties in the description of hadronic interactions in shower development are unavoidable. One has, therefore, to rely on the use of phenomenological interaction models which differ in their predictions in some respect strongly, making the task of retrieving information about individual energy spectra from air shower data even more difficult.

With KASCADE, we have been reconstructing energy spectra and mass composition for five elements representing different mass groups of primary cosmic ray particles, using 7 different high-energy hadronic interaction models and thus helped the model builders to improve their simulation models. All the models used are implemented in the CORSIKA simulation package. CORSIKA (**CO**smic **R**ay event **SI**mulation for **KA**scade) has been written especially for KASCADE and extended since then to become the standard simulation package in the field of cosmic ray air shower simulations (<https://www.iap.kit.edu/corsika/>).

Simulating air showers for KASCADE is a three-step procedure:

- air shower simulation performed by CORSIKA
- detector simulation performed by CRES
- data reconstruction performed by KRETA.

Fig. 2.1. illustrates the parallel workflow of measurements and simulations.

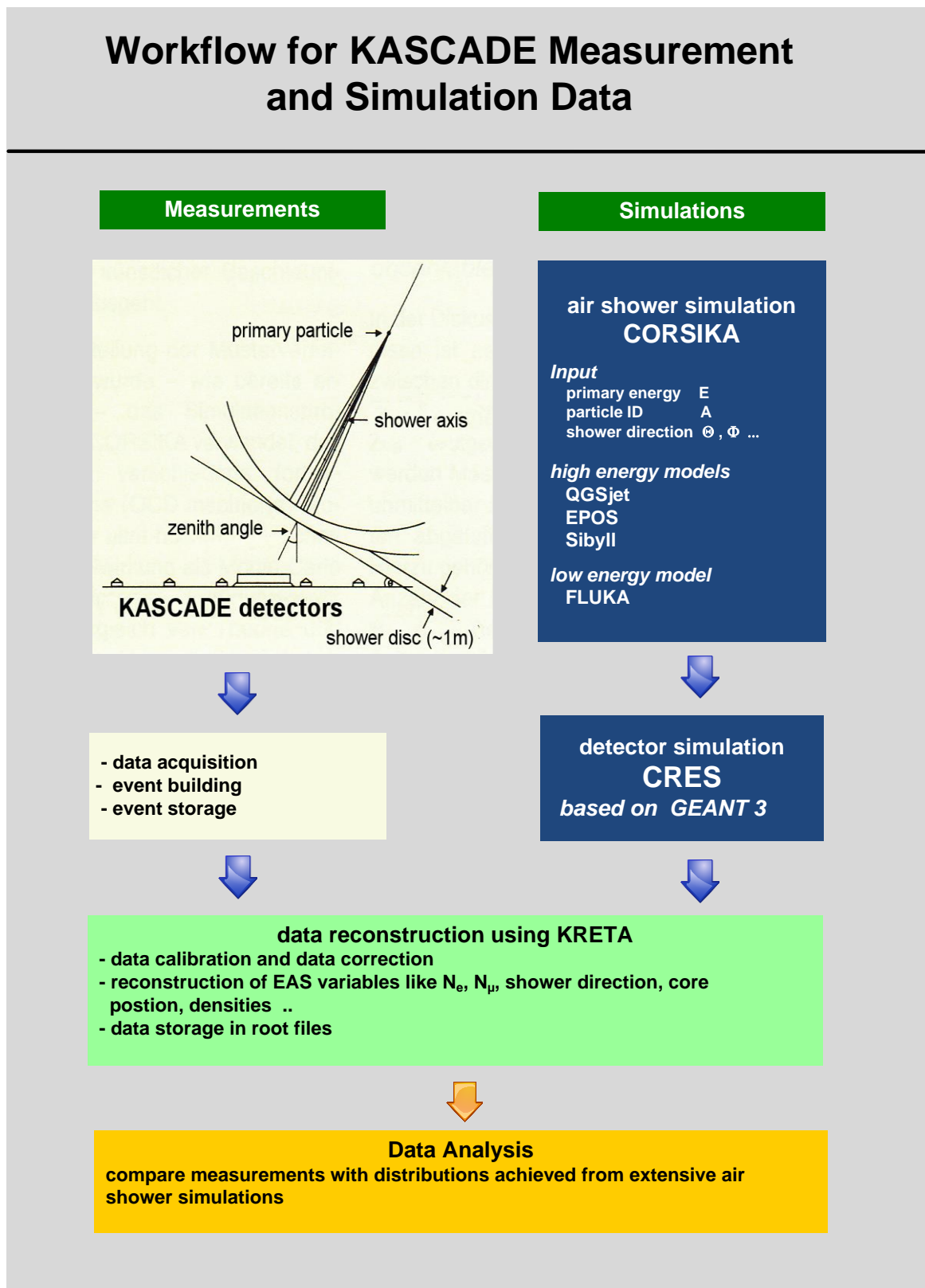


Fig. 2.1

KASCADE data analysis workflow for measurements and simulations

2.1 AIR SHOWER SIMULATIONS USING CORSIKA

CORSIKA (**CO**smic **R**ay event **SI**mulation for **KA**scade;) is a detailed Monte Carlo program to study the evolution and properties of extensive air showers in the atmosphere. The first version 1.0 of CORSIKA is dated from October 26, 1989.

Protons, light nuclei up to iron, photons, and many other particles may be treated as primaries. The particles are tracked through the atmosphere until they undergo reactions with the air nuclei or - in the case of instable secondaries – decay.

The CORSIKA program allows simulating interactions and decays of nuclei, hadrons, muons, electrons, and photons in the atmosphere up to energies of some 10^{20} eV. It gives type, energy, location, direction and arrival times of all secondary particles that are created in an air shower and pass a selected observation level.

A variety of high- and low energy hadronic interaction models is implemented. In KASCADE, we were using seven high-energy models from three different model families:

- QGSjet-II-02 and QGSjet-II-04
- EPOS 1.99 and EPOS-LHC
- SLL 2.1, SIBYLL 2.3, SIBYLL 2.3c and SIBYLL 2.3d

and one low energy model in different versions

- FLUKA.

The data from these six models have been made available the public via the KCDC web portal to enable the users to perform their own mass composition analysis.

For further details, please refer to the CORSIKA users guide and the references therein.

<https://web.iap.kit.edu/corsika/usersguide/usersguide.pdf>

Due to the fast improvement of computing power in recent years detailed simulations of EAS for different primaries, zenith angles and primary energies and of the detailed response of the KASCADE experiment to these events could be performed with sufficient statistical accuracy.

2 Simulations

2.1.1 QGSJET

QGSJET (Quark Gluon String model with JETs) is an extension of the QGS model, which describes hadronic interactions based on exchanging supercritical Pomerons. Additionally QGSJET includes minijets to describe the hard interactions that are important at the highest energies. The current version is QGSJET-II-04 including Pomeron loop and the cross-section is tuned to LHC data.

2.1.2 EPOS

EPOS (Energy conserving quantum mechanical multi-scattering approach, based on Partons, Off-shell remnants and Splitting parton ladders) uses the universality hypothesis to treat the high-energy interactions enabling a safe extrapolation up to higher energies, where cross sections and the particle production are calculated consistently, taking into account energy conservation in both cases.

The current version is EPOS LHC, in which LHC data are taken into account to constrain model parameters.

2.1.3 SIBYLL

SIBYLL is a program developed to simulate hadronic interactions at extreme high energies based on the QCD mini-jet model. For more than 15 years, version 2.1 of Sibyll has been one of the standard models for air shower simulation. Motivated by data of LHC and fixed-target experiments and a better understanding of the phenomenology of hadronic interactions, an improved version of this model, version 2.3, has been released in 2016. SIBYLL 2.3 internally produces charmed particles. Moreover, strange baryons and anti-baryons are accepted as projectiles. Sibyll 2.3c, is a further improvement where particle production spectra have been adjusted to match the expectation of Feynman scaling in the fragmentation region. The main change in the latest model is Sibyll 2.3d with regard to Sibyll 2.3c is in the production of π_0 in jets. In Sibyll 2.3c this production is strongly suppressed due to the interference from a component of the model intended to be active in low energy interactions only.

2.1.4 FLUKA

FLUKA (FLUctuating KAscade) is a package of routines to follow energetic particles through matter by the Monte Carlo method. In combination with CORSIKA only that part is used which

describes the **low-energy hadronic interactions**. FLUKA is used within CORSIKA to calculate the inelastic hadron cross-sections with the components of air and to perform their interaction and secondary particle production, including many details of the de-excitation of the target nucleus.

2.2 DETECTOR SIMULATION WITH CRES

CRES (Cosmic Ray Event Simulation) is a 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**. CRES has been developed, based on the GEANT3 package. CRES accepts simulated air shower data from CORSIKA as input and delivers simulated detector signals. The data structure of the CRES output is the same as from the KASCADE measurements, which means that both are analysed using the same reconstruction program KRETA (*Kascade Reconstruction for ExTensive Air showers*).

CRES is written in FORTRAN 77. It uses CERN library packages and routines.

A detailed description of the detector geometry and the materials is in progress.

2.3 DATA RECONSTRUCTION WITH KRETA

KRETA (Kascade Reconstruction for ExTensive Air showers) reads the rawfz files from measured data and simulations and reconstructs the basic shower observables, storing all the results in the form of histograms and vectors of parameters (ntuples). Fig. 2.1 illustrates the parallel workflow of measurements and simulations.

The reconstruction procedure starts from the signals/energy-deposits in all detector components and determines physical quantities like the number of electrons, of muons, of hadrons, hadronic energies, arrival times, track directions and so on. It develops internally over three levels using an iterative process to come to the final results.

KRETA is written in FORTRAN 77. It uses CERN library packages and routines

2.4 GENERAL INFORMATION ON THE SIMULATED QUANTITIES

2 Simulations

Unlike for measured data where we have calibration data like Air Temperature and more event information like Date and EventTime, we have here some additional information on the shower properties like true primary energy and particle ID derived directly from the air shower simulation CORSIKA or from the detector simulation CRES. From about 200 observables obtained in the analysis of the simulated data, we choose 34 to be published in KCDC. Ten of these parameters are representing the true shower information. These Values are summed up in 'Monte Carlo Information' described in more detail in chapter 6 while chapters 3 to 5 handle the values and data arrays reconstructed with KASCADE, the Central Calorimeter and GRANDE.

It was one of our main goals to publish the simulation data in a format as close as possible to the measured data published with the release **NABOO I.O**, to make it as easy as possible for the users. Thus, we provide six ROOT trees in every download file:

ROOT tree	description
general	all data arrays; run- & event-number
array	all reconstructed KASCADE quantities (E, Xc,Yc,Ze,Az,Ne,Nmu,Age)
grande	all reconstructed GRANDE quantities (Xc,Yc,Ze,Az,Nch,Nmu;Age)
calorimeter	all reconstructed CALORIMETER quantities (Nhad,Ehad)
trmc	all MC information from CORSIKA and CRES (TrEP,TRPP,TrXc,TrYc, TrZe, TrAz,TrNe,TrNg,TrNm,TrNh)
row_map	information to synchronise the trees

Presently we are only offering ROOT files, but we can provide the HDF5 files on request.

2.5 GENERAL INFORMATION ON SIMULATED DETECTOR COMPONENTS

In KASCADE, we have always simulated the response of all active detectors of the 10 components in CORSIKA and CRES storing only the resulting rawfz-files from CRES. This has been done because keeping the CORSIKA files would have been far beyond the scope of our storage capacity while in the rawfz files only the real responses of the active detectors are kept. Furthermore, we have been using one CORSIKA shower several times in CRES thrown at different randomly chosen positions of pre-defined detector areas, different for KASCADE, GRANDE and

2 Simulations

the CALORIMETER. Comparing the time consumption for one shower for CORSIKA, CRES and KRETA, we find that the air shower simulations consume about 90% of the total time nearly independent of the energy of the primary particle. The multiple reuse of one shower is a kind of compromise. On the one hand we want to save computing time and storage space, on the other hand we have to be careful not to insert a ‘bias’, likely when using one air shower too many times. This effect is most important at high energies where we have only few showers simulated.

The table below shows the three published detector components with their simulation areas and the number of reuses per shower. The origin of the coordinate system is the centre of the KASCADE array.

	active simulation area (around the centre of KASCADE)	reused
KASCADE	X: -104m ... +104m ; Y: -104m ... +104m	3
CALORIMETER	X: -11.5m ... +11.5m; Y: -4.81m ... +15.19m	1
GRANDE	X: -630m ... +120m ; Y: -670m ... +120m	10

The different number of reuses is the main reason why we are offering now different ROOT files for the three detector components. Thus, as a user, you will have to decide which is the appropriate detector simulation set, depending on the kind of analysis you want to perform.

As mentioned in chapter 2.4 all ROOT files have the same data structure. This implies that if you analyse for example the KASCADE simulations the results from the GRANDE and the CALORIMETER processors are included as well in the respective root trees.

2.6 SIMULATIONS FOR THE LOPES DETECTOR

For the LOPES detector component presently no simulations are published via the KCDC web portal.

2 Simulations

3 SIMULATED KASCADE DATA IN KCDC

For the KASCADE Array detector (detailed description see KCDC-Manual) we published 11 quantities, 3 of which are data arrays holding information on energy deposits and arrival times in each of the 252 detector stations. Displayed in the table below are as well the two parameters (run and Event numbers) usually referred to as ‘general event parameters’.

Quantity	Description	Unit	ID
Reconstructed Data			
Energy	first order reconstructed Energy	eV	E
Core Position X	location of the reconstructed shower core x-position	m	X_c
Core Position Y	location of the reconstructed shower core y-position	m	Y_c
Zenith Angle	reconstructed zenith angle with respect to the vertical	$^\circ$ (<i>degree</i>)	Z_e
Azimuth Angle	reconstructed azimuth angle with respect to the north	$^\circ$ (<i>degree</i>)	A_z
Electron Number	reconstructed number of electrons (fit)	(<i>number of</i>)	N_e
Muon Number	reconstructed number of muons (fit)	(<i>number of</i>)	N_{μ}
Age	shower shape parameter		Age
e/ γ - energy deposits	energy deposit in MeV / station [252]	(<i>MeV</i>)	$E_{Deposit}$
μ - energy deposits	energy deposit in MeV / station [192]	(<i>MeV</i>)	$M_{Deposit}$
Arrival Times	arrival Times / station [252]	ns	$Arrival$
Event Information			
Run Number	internal simulation counting number	(<i>number of</i>)	R

Quantity	Description	Unit	ID
Event Number	internal simulation counting number	(number of)	Ev

In simulations, every shower has been thrown three times on KASCADE, randomly distributed on an area of 104x104m² as shown in fig 3.1. Displayed as well are the 252 KASCADE detector stations and the fiducial area with the 91m radius cut (dotted line).

The plots shown in this chapter are only examples, based on this subsample of the simulated data for one model (QGSjet-II-04). So, applying user cuts in your own analysis can change these spectra drastically.

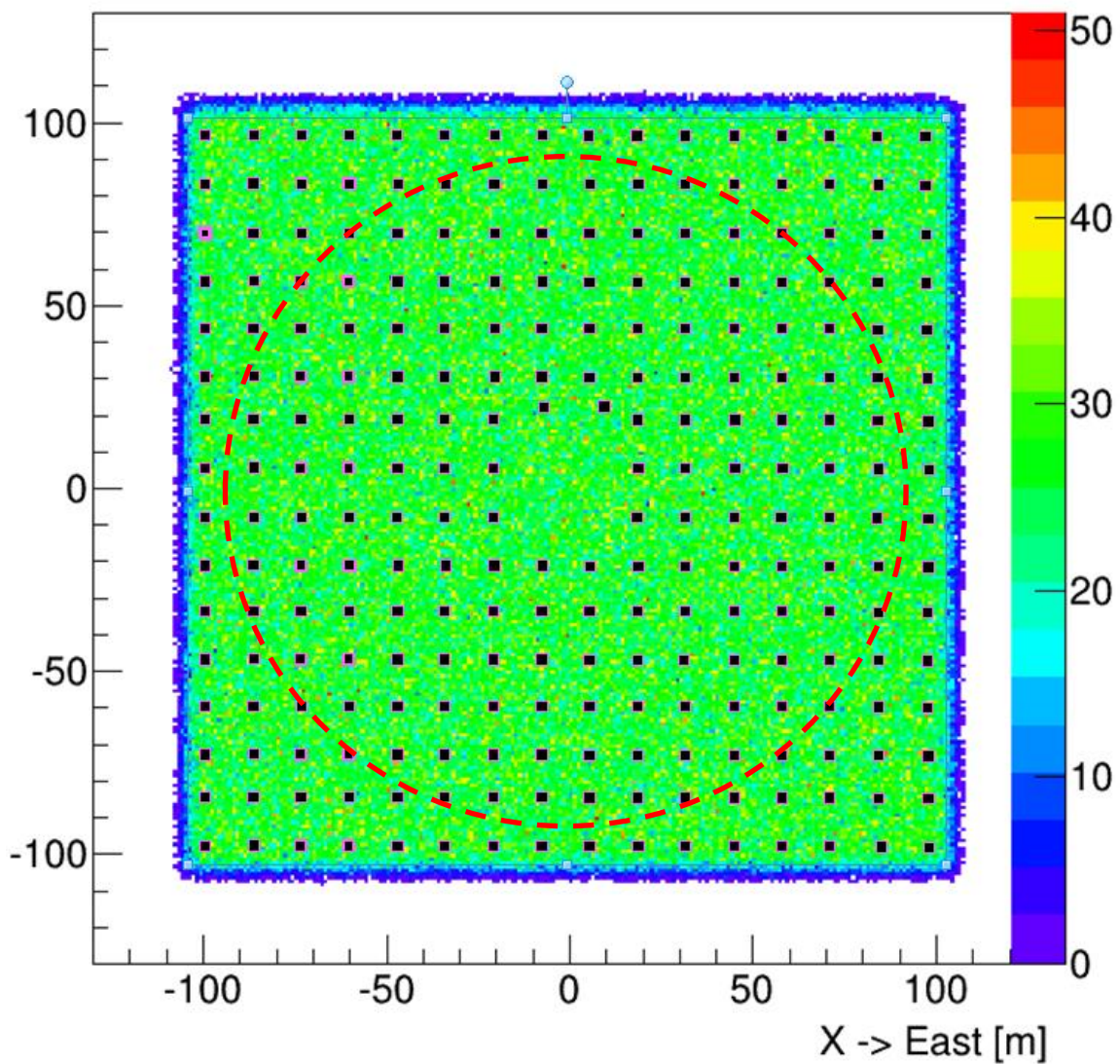


Fig. 3.1 *Distribution of the shower cores of all simulated showers on KASCADE without any cuts. Shown also are the KASCADE detector stations and fiducial area (dashed red line)*

3.1 ENERGY (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 large 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. By using both 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.

3.1.1 ENERGY ESTIMATION

To get a rough energy estimation the comparison of the reconstructed data and the CORSIKA simulations have been used by applying the hadronic interaction model of QGSjet-II-02 (Quark-Gluon-String Model, version II-2) for laboratory energies above 200GeV and the low energy model Fluka 2002_4 for energies below. The simulations cover the energy range of $1 \cdot 10^{14}$ to $3 \cdot 10^{18}$ eV with zenith angles in the interval 0° - 42° . The spectral index in the simulations was $\gamma=-2$ to save time and disk space and then corrected for the real spectral index of the cosmic rays to $\gamma=-2.7$.

For the Parametrisation, the air showers are divided into two zenith angel ranges, from 0° to 18° and from 18° to 25° . Both angular bins have the same acceptance. The selected data in the energy range $10^{15} < E_0 < 3.16 \cdot 10^{18}$ eV are divided in 15 logarithmically equidistant intervals, where the mean values of e/γ - and μ -distributions are determined.

3.1.2 FORMULA FOR ENERGY ESTIMATOR

atmospheric depth at KASCADE level (110 m.a.s.l.)

$$D = (-186.5562) + (1222.6562) \cdot \exp(-110 \cdot 100 / 994186.38)$$

$$x_{atte} = 158.0$$

$$x_{attm} = 823.0$$

transform to average sizes for vertical showers 0-18 deg

$$dwb1 = (D / \cos(\theta_{rad})) - (D \cdot 1.025)$$

$$\lg(N_e) = \lg(N_e) + (dwb1 / x_{atte} / \log(10.))$$

$$\lg(N_\mu) = \lg(N_\mu) + (dwb1 / x_{attm} / \log(10.))$$

$$\lg(E) = 1.93499 + 0.25788 \cdot \lg(N_e) + 0.66704 \cdot \lg(N_\mu) + 0.07507 \cdot \lg(N_e)^2 + 0.09277 \cdot \lg(N_\mu)^2 - 0.16131 \cdot \lg(N_e) \cdot \lg(N_\mu)$$

The spectrum of the reconstructed energy of the primary particle for KASCADE based on this formula is shown in Fig. 3.1.1 (red). Displayed as well is the spectrum of the incident particles after the standard quality cuts of KASCADE have been applied i.e. the true primary energy (black). Clearly visible also is that the full efficiency of the reconstruction is reached at about 10^{15} GeV.

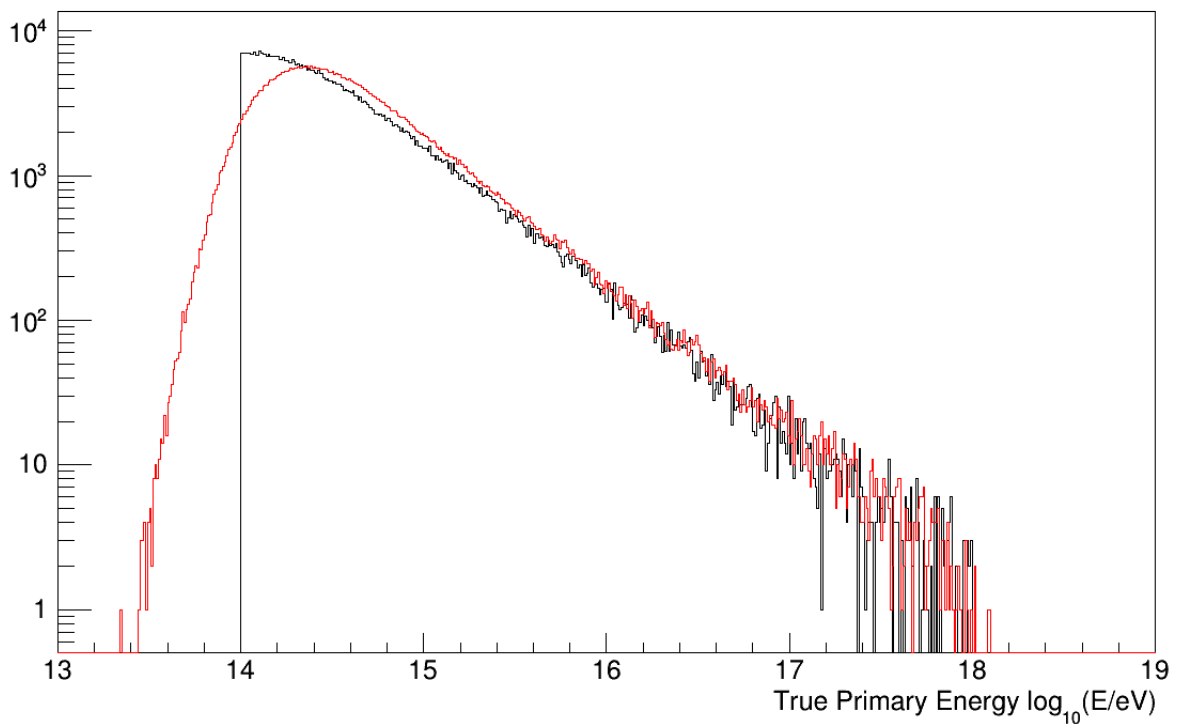


Fig. 3.1.1 *The reconstructed energy spectrum (red) and the true energy spectrum (black) in log-log scale for reconstructed protons*

Fig. 3.1.2 shows the quality of the energy reconstruction compared to the true primary energy of the incident protons. The red dashed line denotes the expected values.

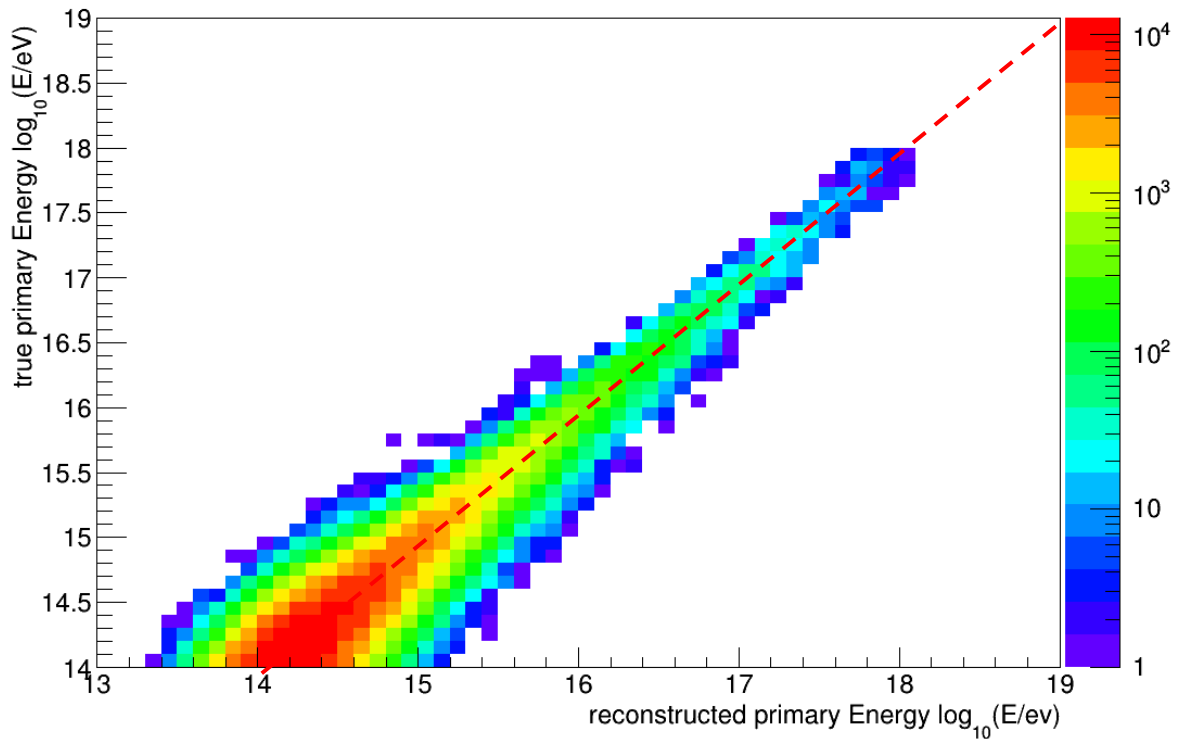


Fig. 3.1.2 *True primary energy of the incident particle vs reconstructed primary energy for proton-induced showers. The dashed red line denotes the expected value.*

3.2 NUMBER OF ELECTRONS AND NUMBER OF MUONS (N_e , N_{μ})

From the KASCADE simulations we derive the energy deposits of charged particles and muons at ground level, as well as their arrival time. From these data, the arrival direction of the shower, its impact point on ground (shower core) and the total number of electrons and muons in the shower are reconstructed. Details see the ‘KCDC-Manual’

Fig. 3.2.1 shows the N_e spectrum of the simulated proton showers reconstructed with KRETA (red) and the true N_e spectrum (black). The quality cut is at $N_e=100$. The excellent agreement of the reconstructed number of electrons with the true number as shown in fig. 3.2.2 proves the quality of the energy calibration and the reconstruction. The dashed line denotes the expected values.

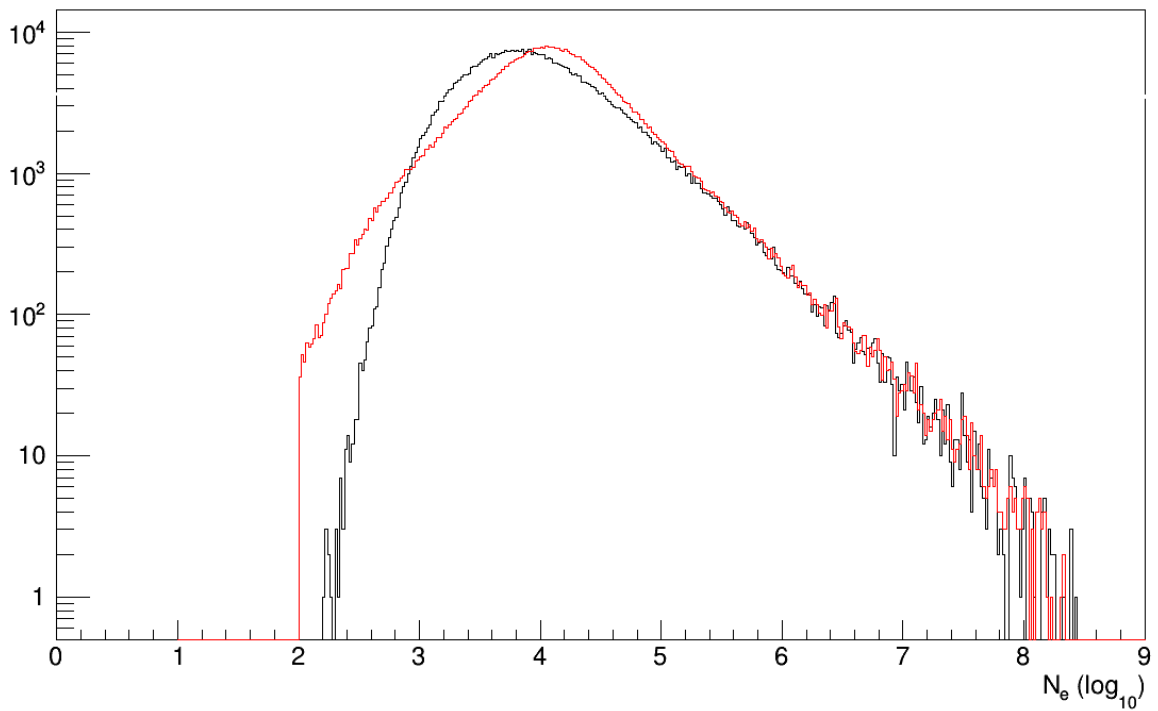


Fig. 3.2.1 *The spectrum of the reconstructed number of electrons*

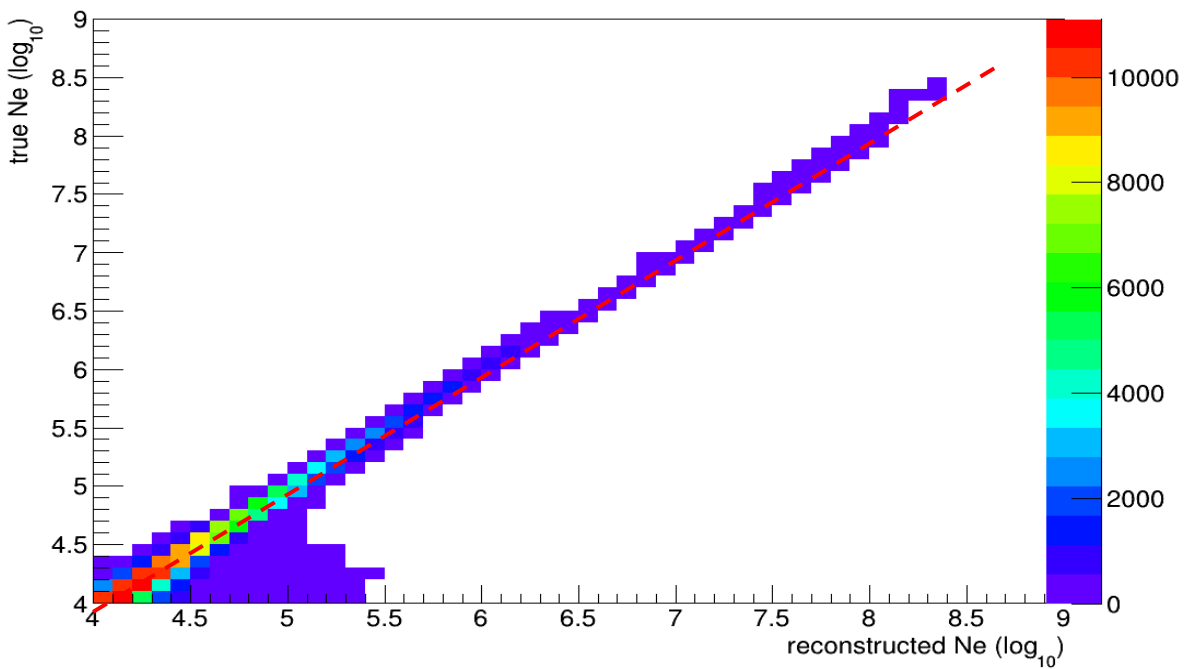


Fig. 3.2.2 *N_e Spectrum; true number of electrons vs N_e after reconstruction for proton induced showers. The dashed red line denotes the expected values.*

In fig. 3.2.3 the N_μ spectrum of the simulated proton showers reconstructed with KRETA (red) is displayed and the true N_μ spectrum (black). The quality cut is at $N_\mu=400$. The structure

clearly visible at low energies is an artefact for low muon numbers close to the threshold. The good agreement of the reconstructed number of muons with the real number is shown in fig. 3.2.4.

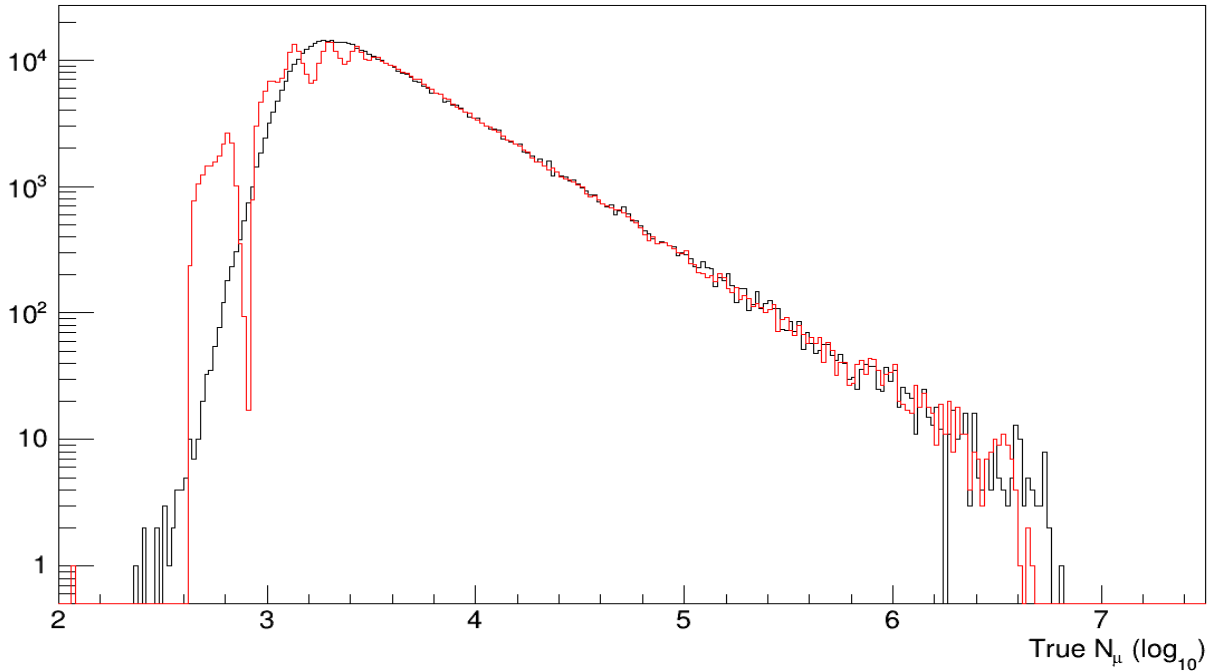


Fig. 3.2.3 *The spectrum of the reconstructed number of muons*

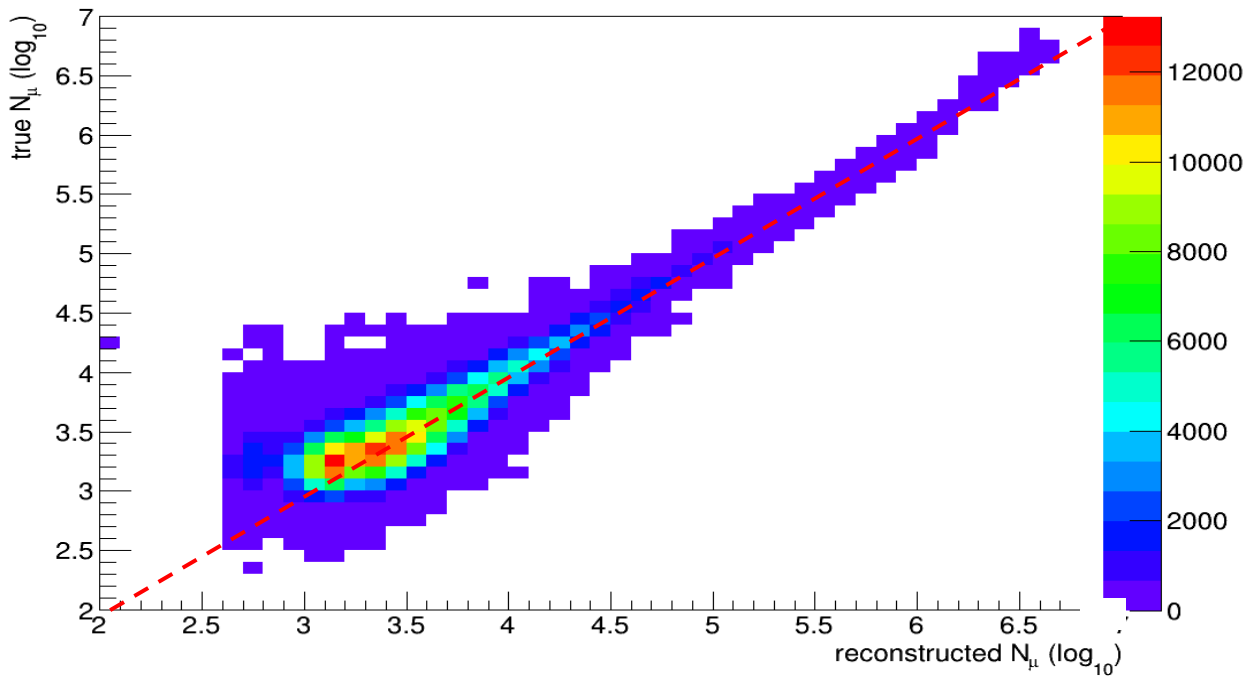


Fig. 3.2.4 *N_μ Spectrum; true number of muons vs N_μ after reconstruction for proton-induced showers. The dashed red line denotes the expected value.*

In fig. 3.2.5 the $lgN_\mu - lgN_e$ distribution from CORSIKA simulations as reconstructed by KRETA is displayed.

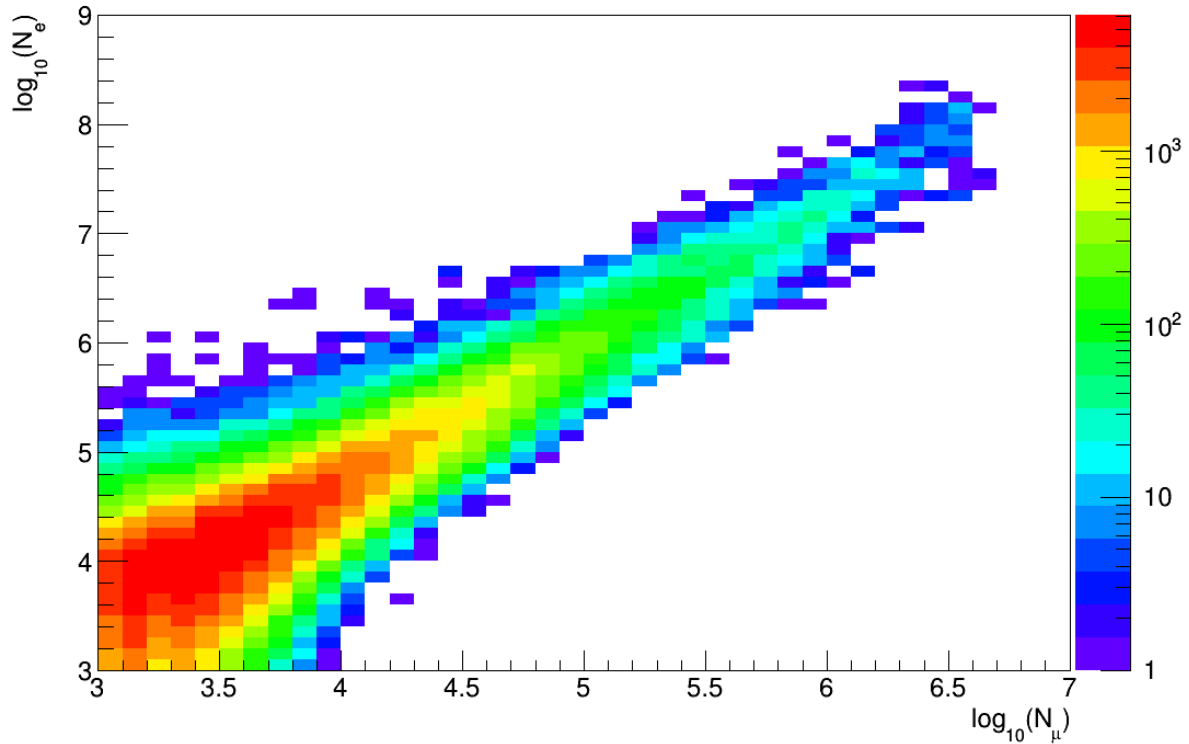


Fig. 3.2.5 $lgN_\mu - lgN_e$ distribution reconstructed from KASCADE simulations

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 that 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 0.1 to 1.48. Common shower values however range from 0.6 to 1.3. Lower values describe steeper lateral distributions.

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.

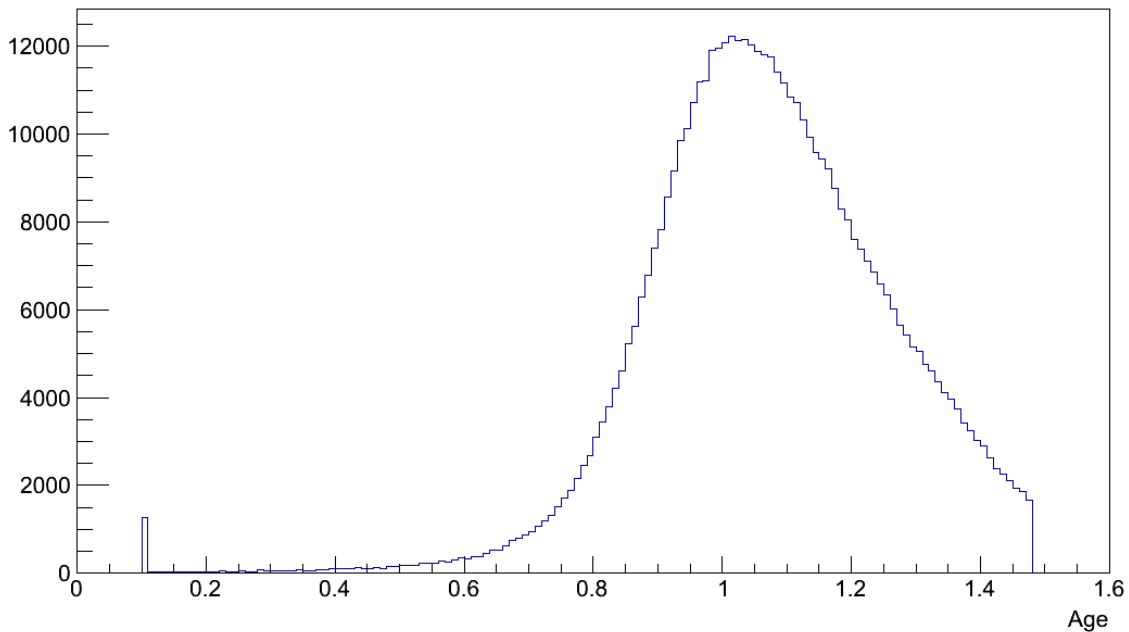


Fig. 3.3.1 *The AGE distribution from the modified NKG function for reconstructed proton showers.*

3.4 SHOWER CORE POSITION (X_C, Y_C)

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

For the reconstruction of the core position in the KASCADE array basically the energy deposits in every detector station are taken. By means of a *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 precision of about 1m. In addition, this method offers a simple approach to identify events with subcores.

In figs 3.4.1. and 3.4.2 the distributions of the X- and Y-core positions are shown. The regular structure is caused by an artefact in the reconstruction algorithm, which causes the centre of the shower core to be drawn towards the stations with the highest measured energy deposit. This effect is particularly pronounced for low energies, also clearly visible in figs 3.4.3 to 3.4.5. At high energies, the centre of the shower core is drawn between the stations with the highest measured energy deposits.

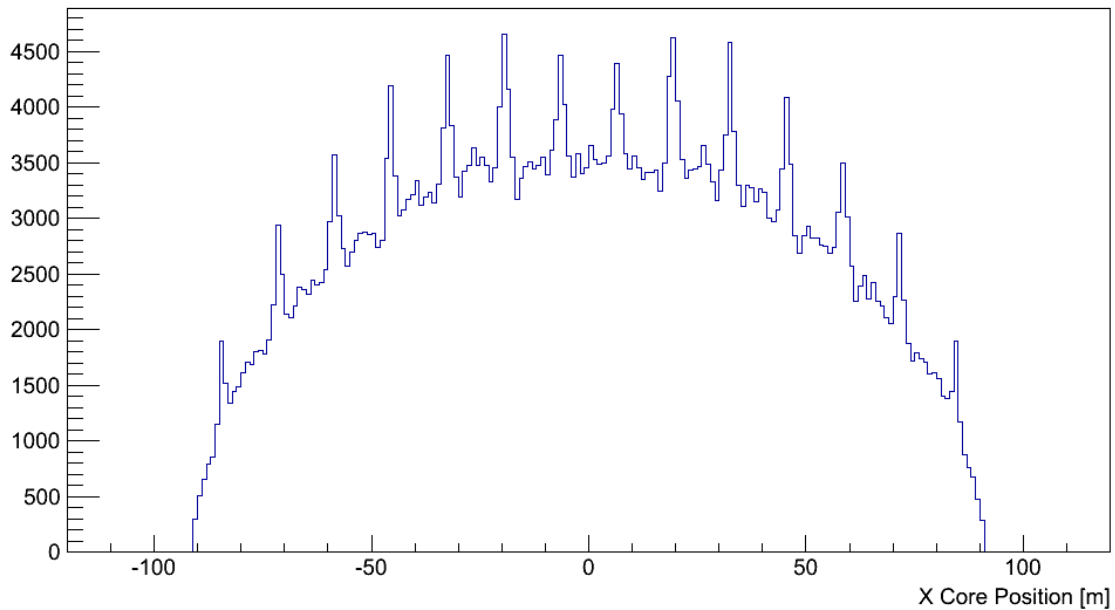


Fig. 3.4.1 *X-core position of reconstructed proton showers*

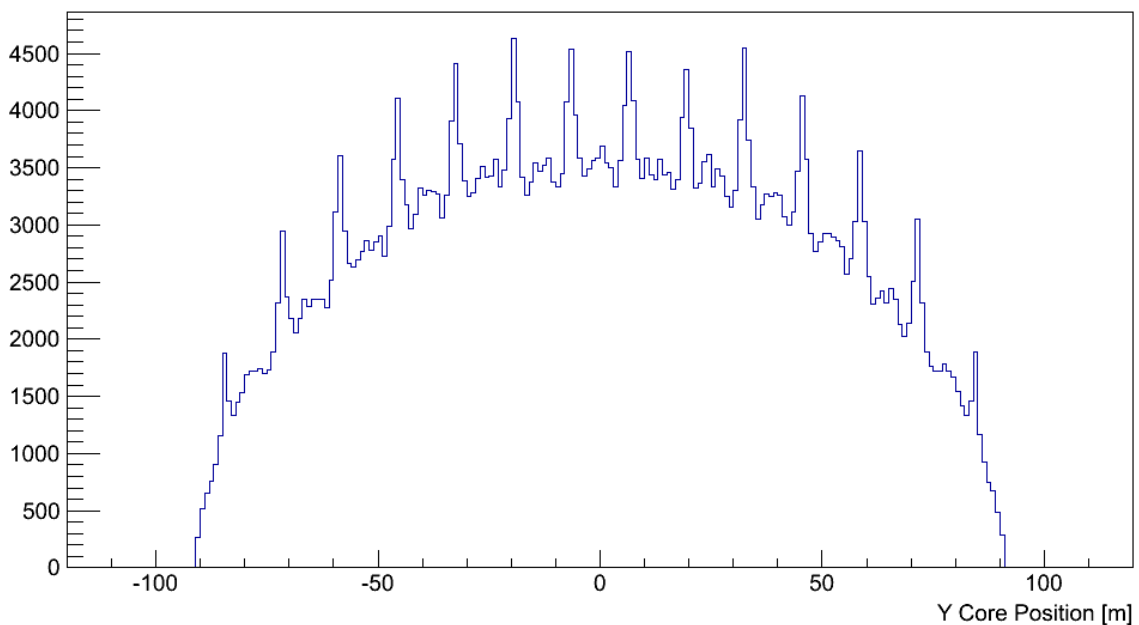


Fig. 3.4.2 *y-core position of reconstructed proton showers*

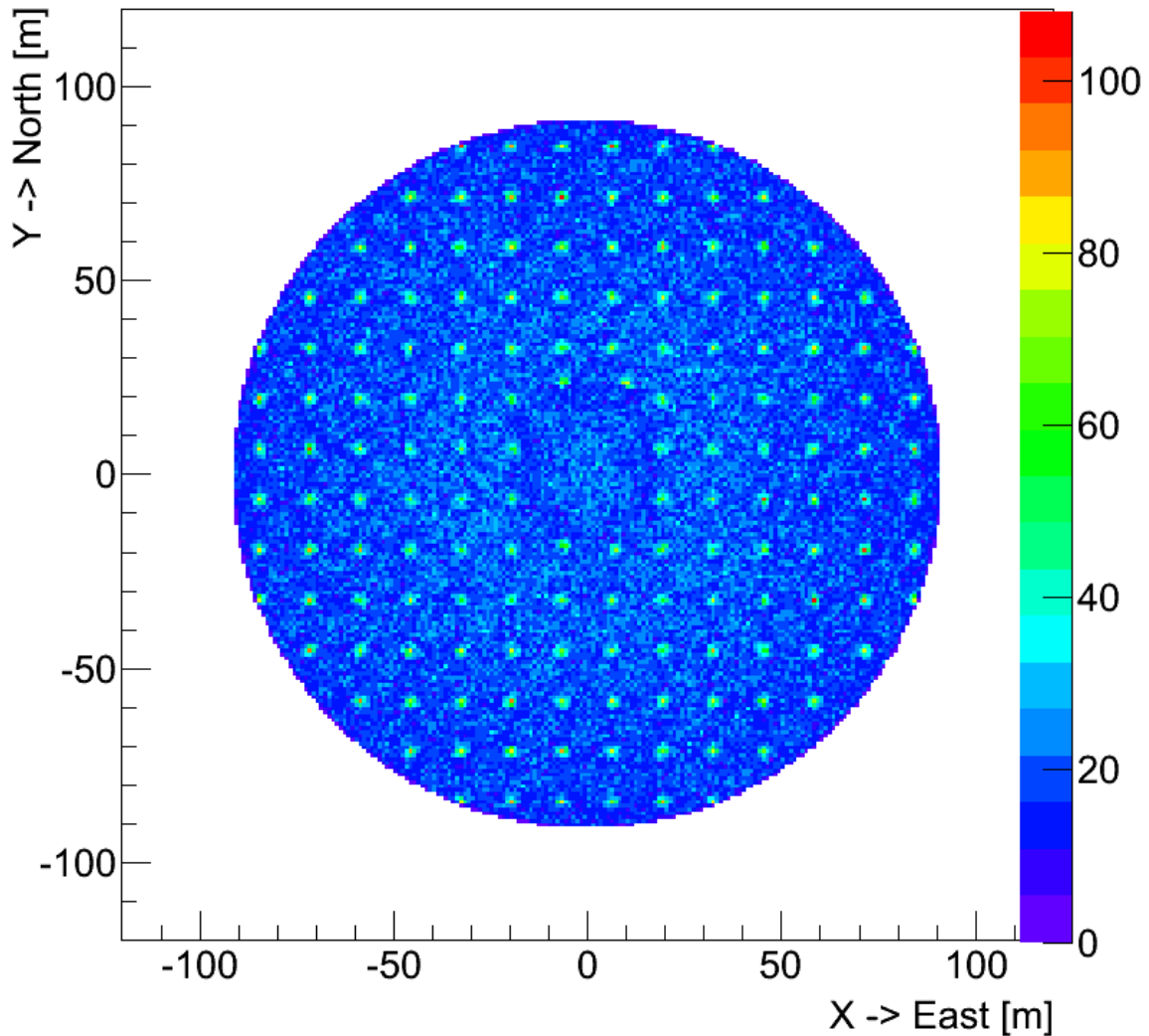


Fig. 3.4.3 *Shower core distribution for reconstructed proton showers*

The distribution of the shower core is plotted in the fig. 3.4.3. Extensive air showers with a core position outside the detector area have a great probability for being incorrectly reconstructed. Therefore, only showers with a maximum core distance less than 91 m radius from the centre of the detector area are taken into account which reduces the fiducial area by about 35%. In the centre of the array the Central Calorimeter is located, thus four stations are missing. The two detector stations north of the Central Calorimeter are a little dislocated because of the main building.

The quality of the reconstruction is shown in figs 3.4.4 to 3.4.6. In figs. 3.4.4 & 3.4.5 the X- and Y-positions are displayed versus the true positions of the simulated shower core, while in fig. 3.4.6 the absolute deviation of the reconstructed shower core position is shown. The true core position is derived from CRES detector simulations, where the shower core is randomly distributed over a pre-defined detector area (see also fig 3.1).

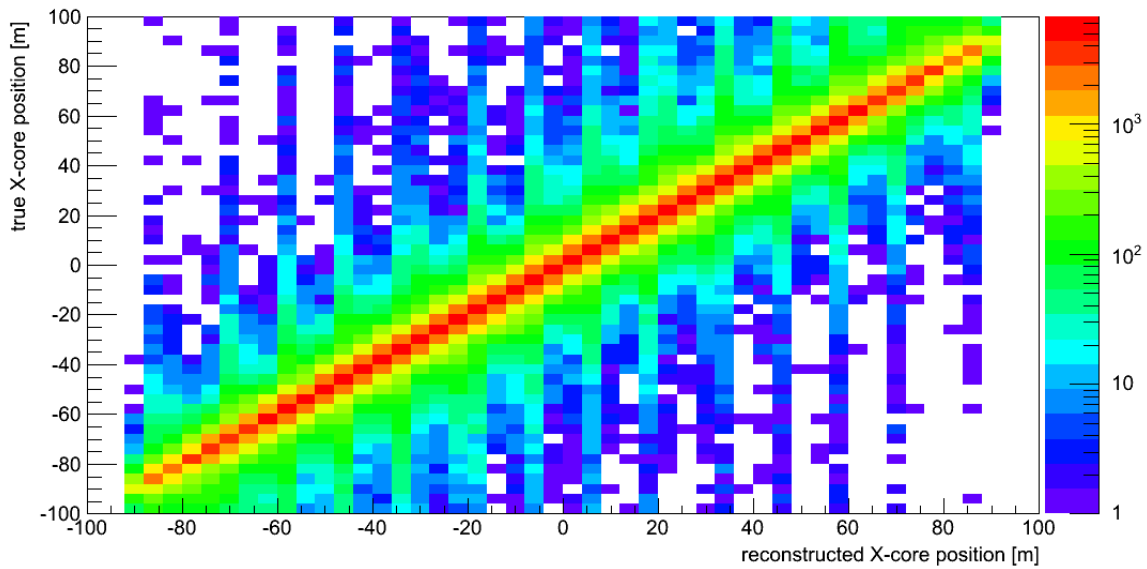


Fig. 3.4.4 *True X-shower core position vs reconstructed X-shower core position for proton induced showers*

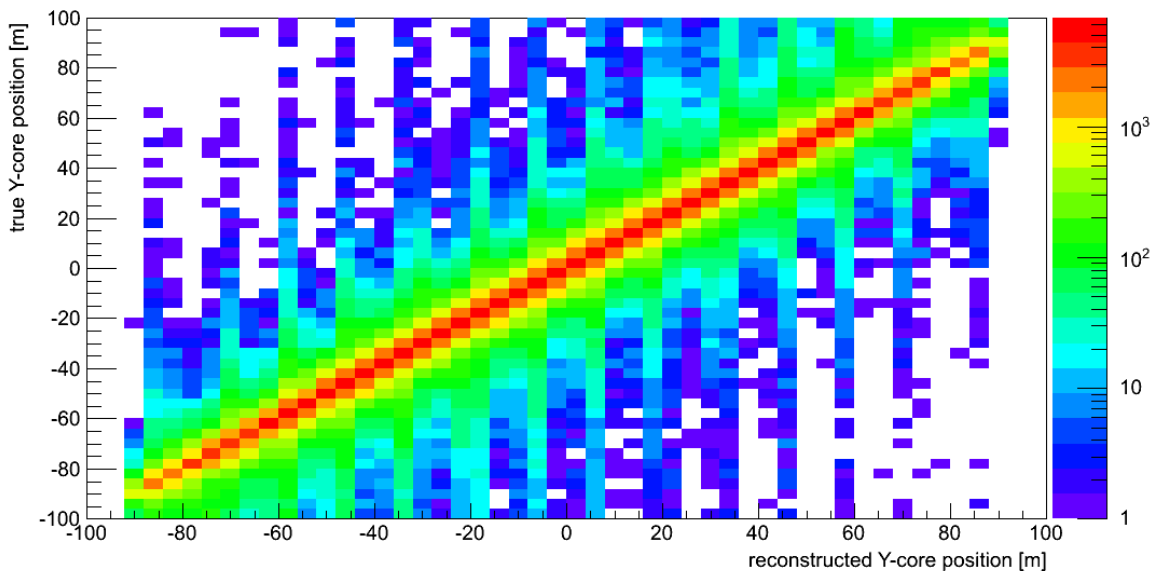


Fig. 3.4.5 *True Y-shower core position vs reconstructed Y-shower core position for proton induced showers*

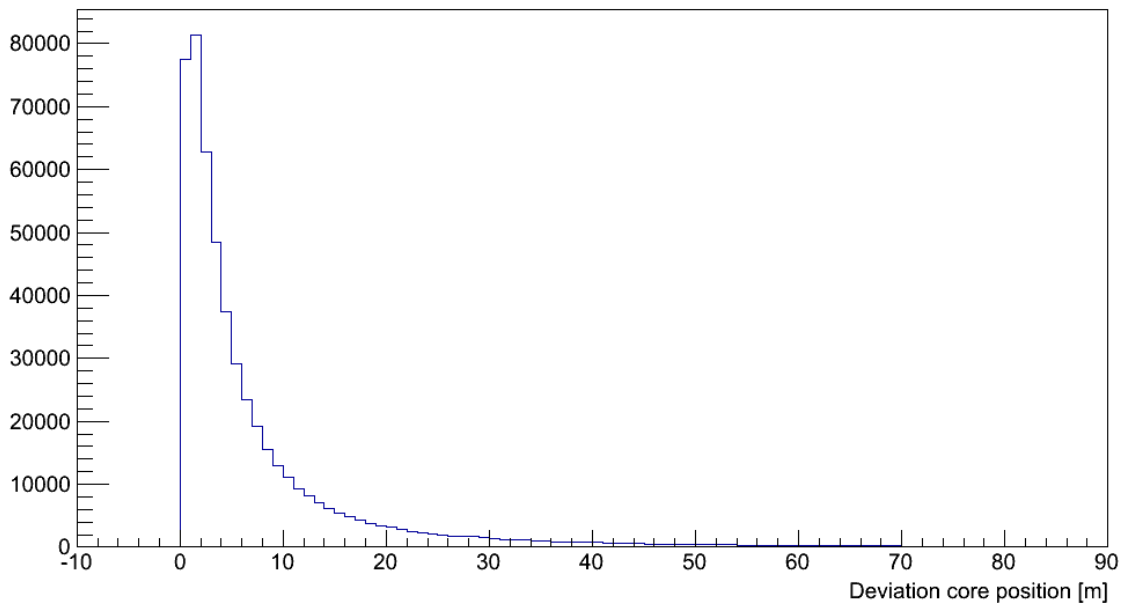


Fig. 3.4.6 *absolute deviation of the shower core position between true and reconstructed core positions*

3.5 SHOWER DIRECTION (ZE, AZ)

From the KASCADE simulations we get the arrival times and the energy deposits of air shower particles. The shower direction is determined by evaluating the arrival times of the first particle in each detector station. To increase the accuracy, the energy deposits are taken into account when the direction of the shower disk is calculated.

The angular resolution drops significantly above about $\theta > 40^\circ$, caused by the fact that the reconstruction algorithm has been fine-tuned to zenith angles below 40° . Even though the data sets include published with KCDC include events with zenith angles up to 60° , the simulations are limited to 42° because the KASCADE collaboration has set limits in their analysis to 40° . This restriction reduces the number of analysed showers by about 5% but saves a lot of time and disk space in simulations.

In KASCADE coordinates, the zenith angle is measured against the vertical direction, which means that $\theta = 0^\circ$ 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 Array has an offset of about $+15^\circ$ against the real northern direction, caused by the fact that the conditions of the location (KIT, Campus North) allows only this orientation. This offset is corrected for in the data analysis. The unit of the azimuth and zenith angle is $[\circ]$.

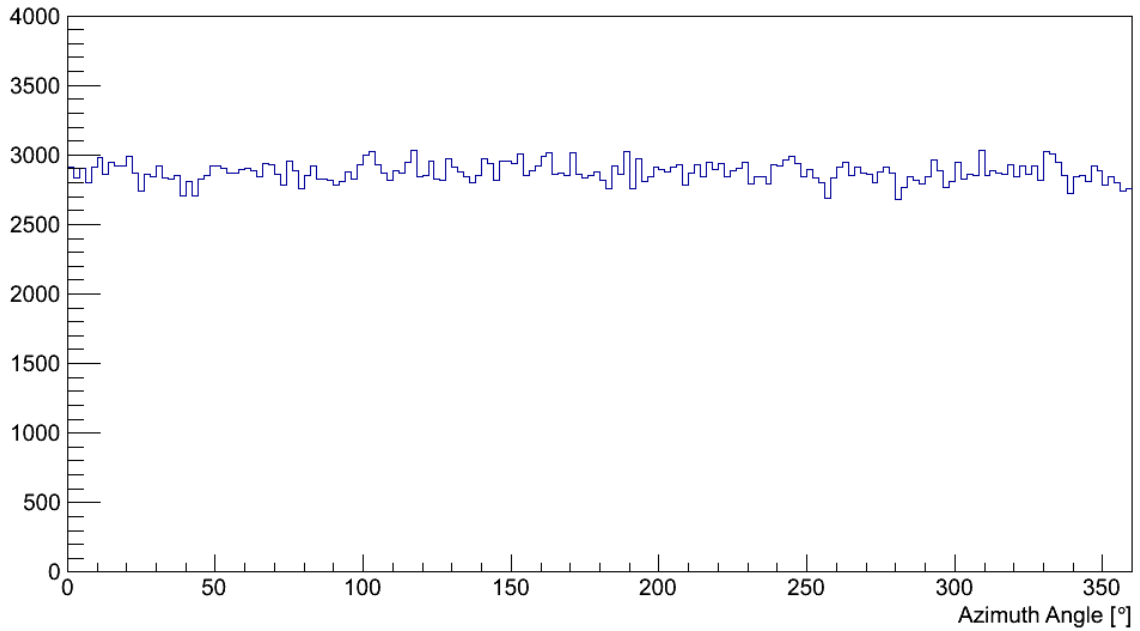


Fig. 3.5.1 *The distribution of the reconstructed azimuth angle for proton induced showers*

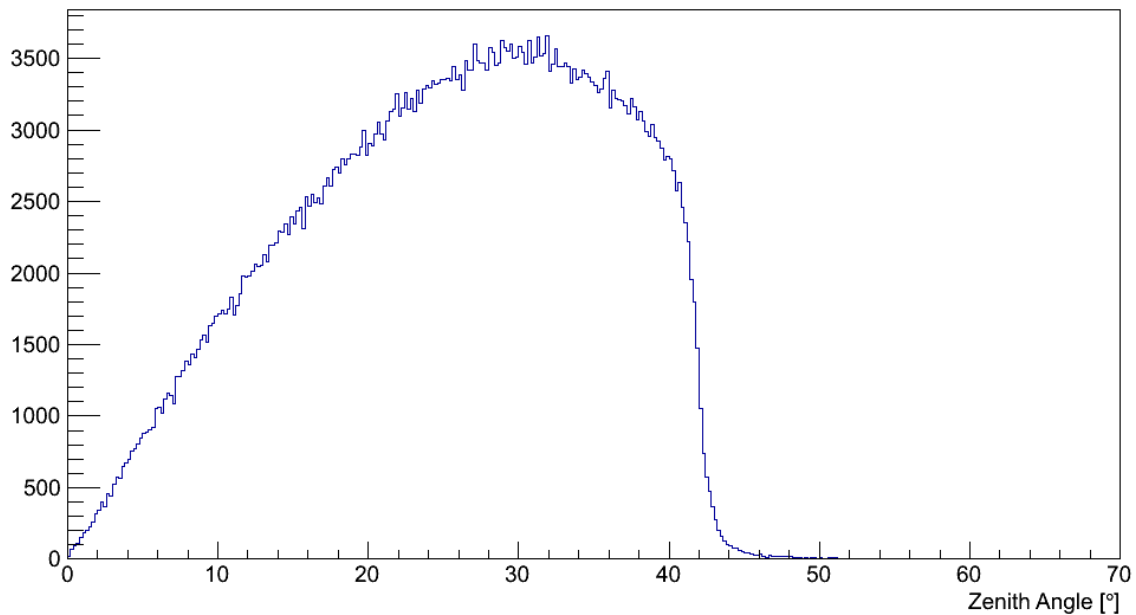


Fig. 3.5.2 *The distribution of the reconstructed zenith angle for proton induced showers*

In fig. 3.5.1 the distributions of the azimuth angle for simulated protons is shown. The distribution of the simulated and reconstructed zenith angle shown in fig 3.5.2.

The quality of the angular reconstruction is shown in figs 3.5.3 and 3.5.4 where Z_e - and the A_z -angles are displayed versus the true shower directions. The true angles are input parameters for the air shower simulation program CORSIKA.

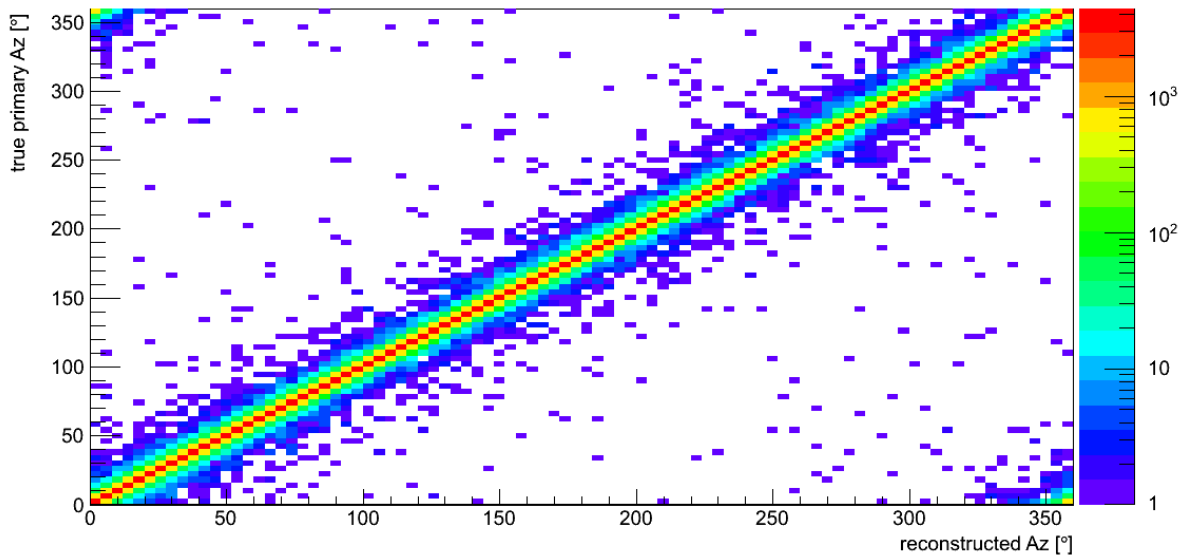


Fig. 3.5.3 *True A_z angle vs reconstructed azimuth angle for proton induced showers*

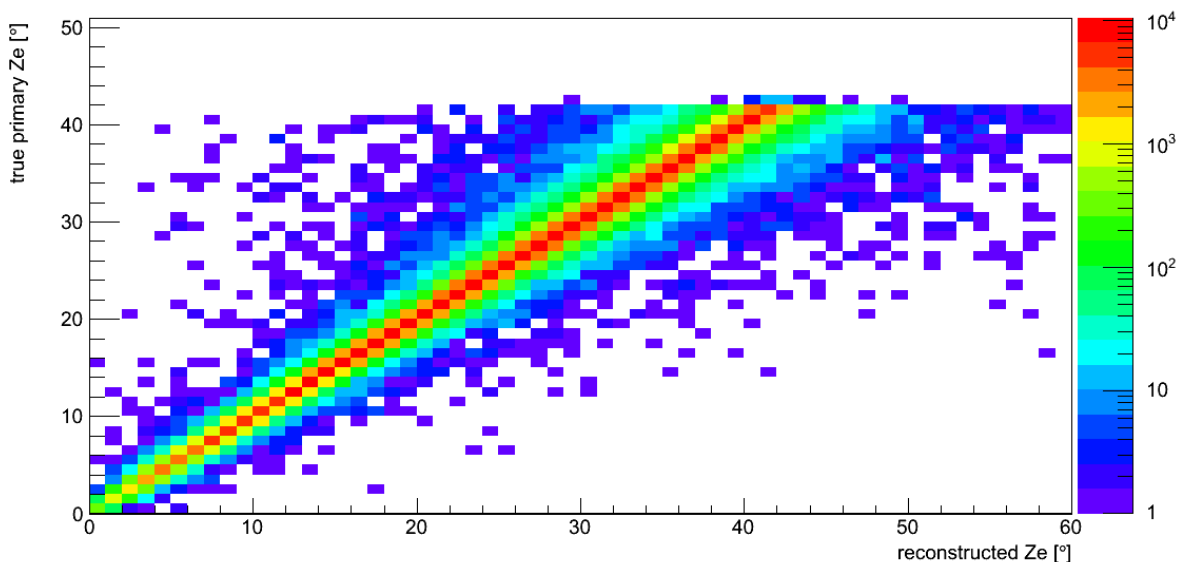


Fig. 3.5.4 *True Z_e angle vs reconstructed zenith angle for proton induced showers*

3.6 ENERGY DEPOSITS PER STATION (EDEPOSIT, MDEPOSIT)

The energy deposits of each single detector station are simulated in the e/γ - and in the μ -detectors.

While in measurements a detector station flagged 'inactive' or 'overflow' was excluded from the data analysis, it is different in simulations. Here we do not have any 'inactive' detector stations to be excluded. Stations with energy deposit overflows are excluded from the data analysis in KRETA **but included in the data sets** because they might hold valuable information depending on the analysis performed by the KCDC user.

Detector stations which had no signal above the threshold are set to $E_{\text{dep}}=0$ MeV.

3.6.1 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. For simulations all stations are always active which implies that the number of detector stations with valid energy deposit information (**EDepositN**) is always 252.

Thus, 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]

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

The number of active e/γ -detector stations stored in **EDepositN** is for simulations always 252 because there is no feature implemented in the simulation dealing with inactive stations.

Note: This value is always shipped with ' e/γ Energy Deposit' Quantity in the root files.

3.6.1.2 Number of e/γ -detector stations with hits

The distribution of the number of e/γ -detectors with $E_{Deposit} > 0$ is given in fig 3.6.1.

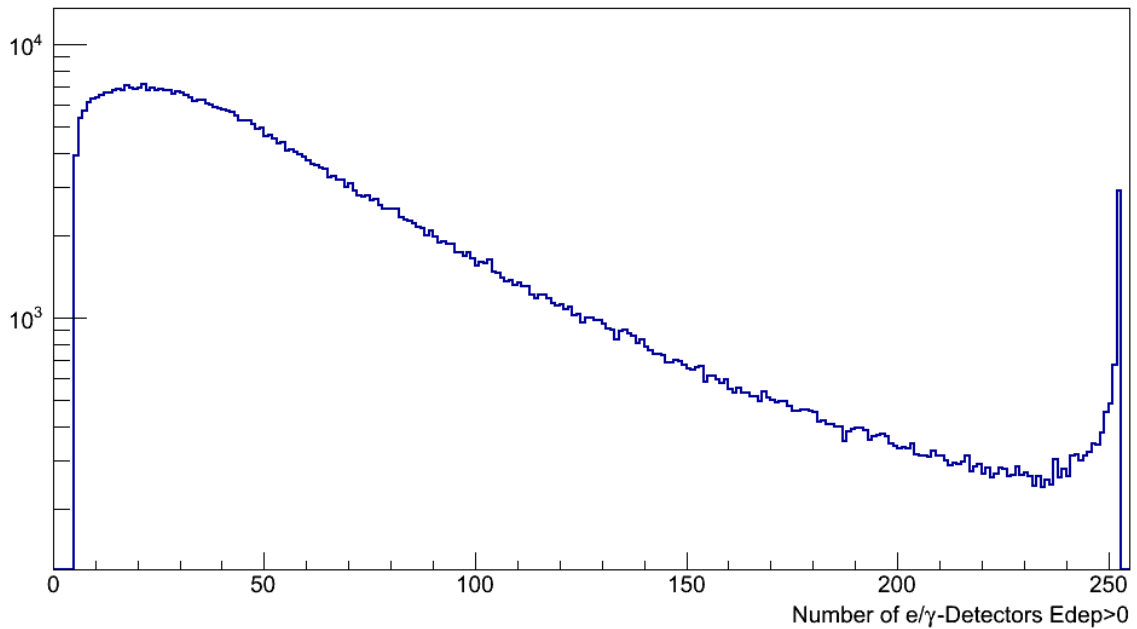


Fig. 3.6.1 *Distribution of the true number of e/γ -detector stations with hits*

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

The Energy deposits are directly taken from the simulations for each detector station. **EDeposit** values are given in MeV. In fig 3.6.2 the energy deposits for simulated proton induced showers are plotted. The overflow cut is set to 10 GeV.

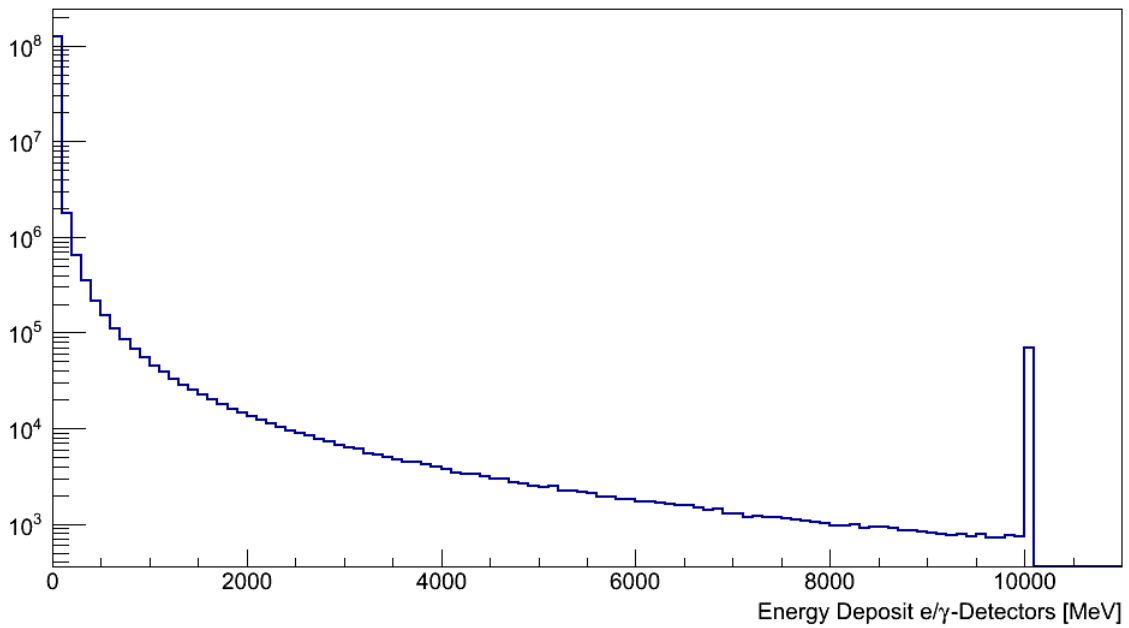


Fig. 3.6.2 *Distribution of the true e/γ-Energy Deposits of all active stations*

3.6.1.4 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 7.3 and Appendix A.

Fig 3.6.3 shows the distribution of station IDs of the active e/γ-detector stations. The distribution is flat for simulations because we do not include inactive stations in our detector simulations. Stations with energy deposits above 10 GeV are active too, the deposits are not taken into account for analysis but are included in the data samples.

Note: This value is always shipped with ‘e/γ Energy Deposit’ Quantity in the root files.

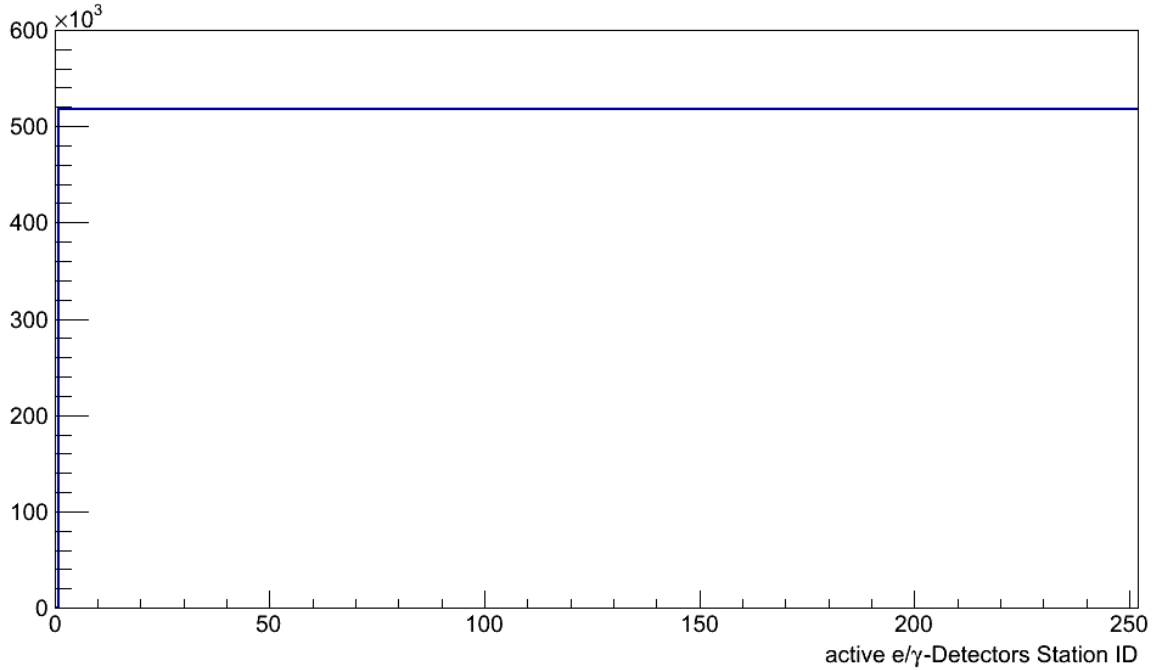


Fig. 3.6.3 *Distribution of station IDs for active e/γ-detector stations*

For further studies the effective e/γ –detector area for a given station can be derived from the station ID. As described in chapter 2 of the KCDC-Manual two different detector setups are realised in the KASCADE array. The inner 4 clusters consist of only 15 stations, (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. 3.6.4). The table below shows the correlation between station ID and effective detector area.

Station ID	Area [m ²]	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

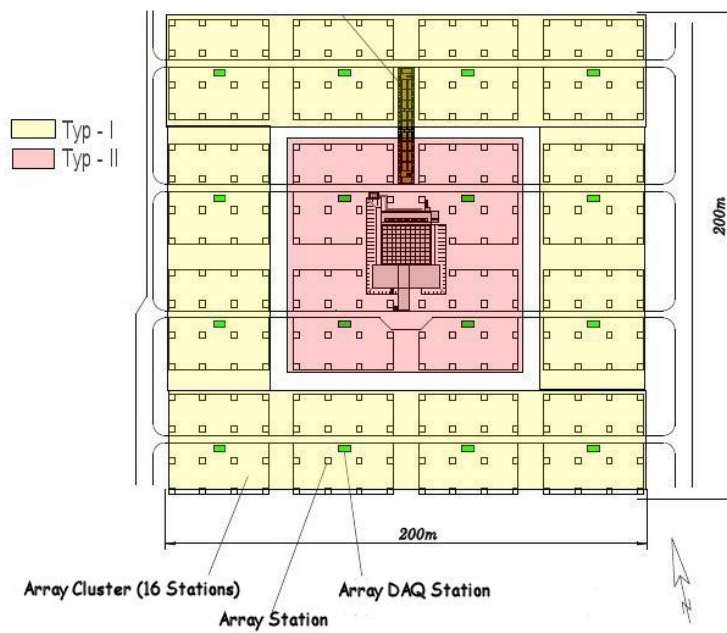


Fig. 3.6.4 *Array setup; schematic view of the KASCADE detector array*
yellow: two e/γ-detectors, 1.57m²; red: four e/γ-detectors, 3.14m² per station;

3.6.1.5 Example

As an example for energy deposits in the KASCADE array the **EDeposit** distribution of two events is shown in fig. 3.6.5. The warmer the colour the higher the deposited energy in the 252 e/γ-detector stations.

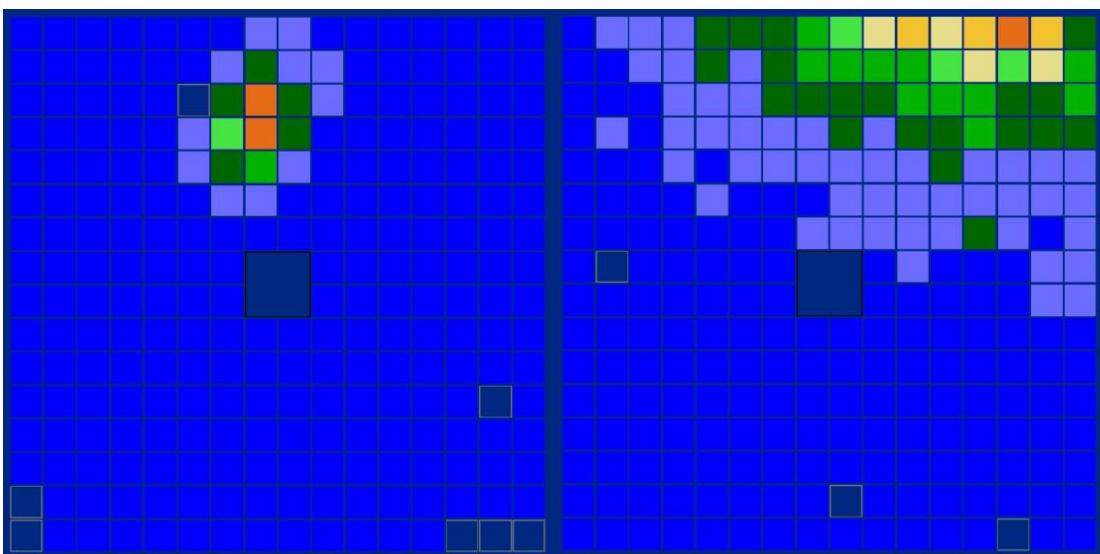


Fig. 3.6.5 *Two examples of e/γ-energy deposits in the KASCADE array*

3.6.2 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. For simulations all stations are always active which implies that the number of detector stations with valid energy deposit information (**MDepositN**) is always 192.

Thus, you will always be supplied with 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 [1 ... 252]

3.6.2.1 Number of active μ -detector stations (**MDepositN**)

For simulations, all μ -detector stations are always active which implies that the number of stations with valid energy deposit information (**MDepositN**) is always 192. As the detector station IDs are the same as for the e/γ -energy deposits, the range of the IDs is up to 252 because the four inner cluster (64 stations) are not equipped with μ -detectors.

Note: This value is always shipped with the ‘**Muon Energy Deposit**’ Quantity in the root files.

The distribution of the number of μ -detectors with energy deposit $MDeposit > 0$ in this event is given in fig 3.6.6.

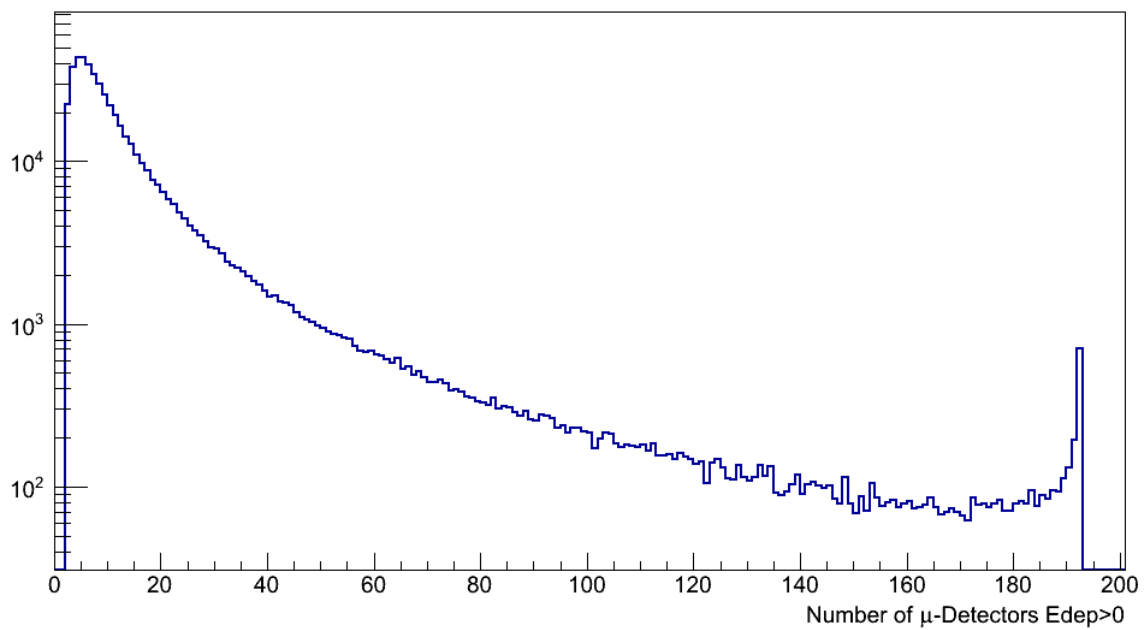


Fig. 3.6.6 *Distribution of the true number of μ -detector stations with hits*

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

The Energy deposits are directly taken from the simulations for each detector station. **MDeposit** values are given in MeV. In fig 3.6.7 the energy deposits for simulated proton induced showers are plotted. The overflow cut is set to 400 MeV.

Note: Muon energy deposits within a 40m radius around the reconstructed shower core are usually not used for data analysis because of the saturation and the punch through effects, which cannot be estimated, but is included in the simulation data sets.

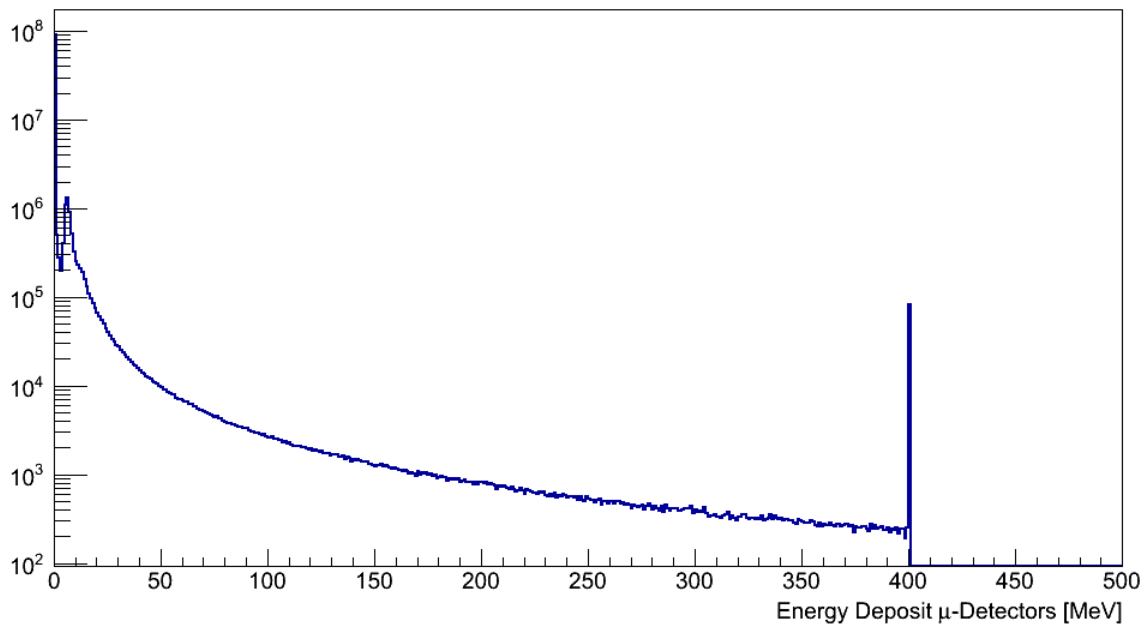


fig. 3.6.7 *Distribution of the true μ -energy deposits of all active stations*

3.6.2.3 Station ID (MDepositS)

The *station ID* (same as for e/γ -detectors in 3.6.1.4) 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 7.3 and Appendix A.

Fig 3.6.8 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-Manual, chapter 2.2). The otherwise flat distribution in the simulation is due to the fact, that there are no inactive stations in simulations. Stations with energy deposits above 400 MeV and stations within a 40m radius from the shower core are not taken into account for the analysis but are included in the data sample.

The effective μ -detector area for all 192 stations is 3.24 m² (yellow area in fig 3.6.4).

Note: This value is always shipped with the 'Muon Energy Deposit' Quantity in the root files.

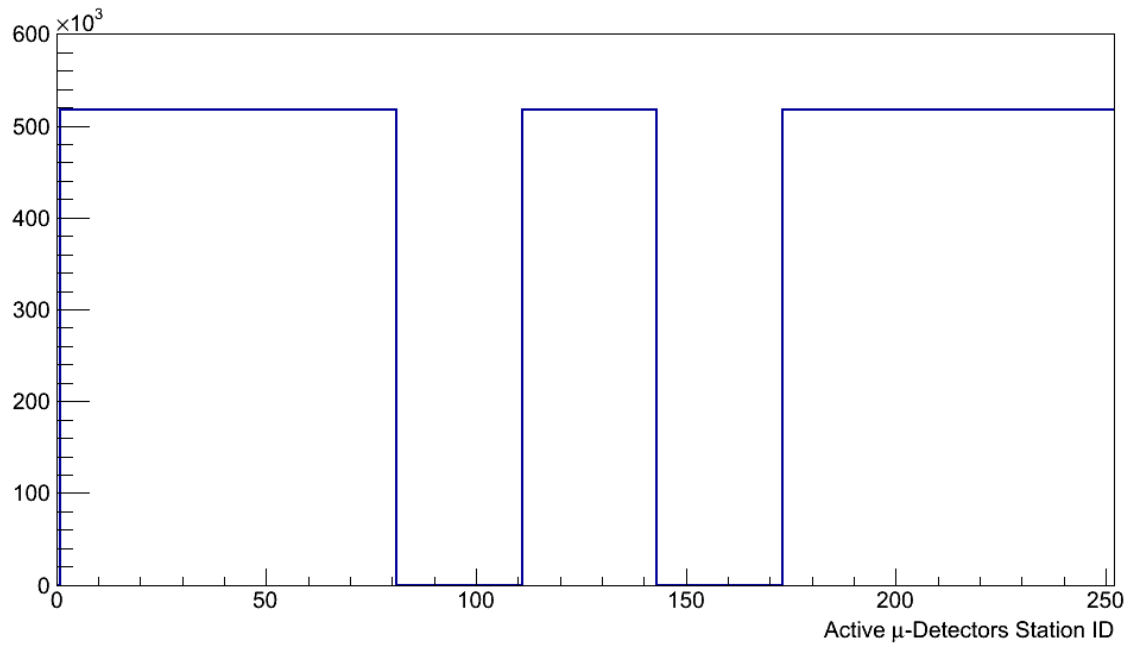


Fig. 3.6.8 *Distribution of station IDs for active μ -detector stations*

3.6.2.4 Example

As an example for energy deposits in the KASCADE array the **MDeposit** distribution of two events is shown in fig. 3.6.9. The warmer the colour the higher the deposited energy in the 192 μ -detector stations.

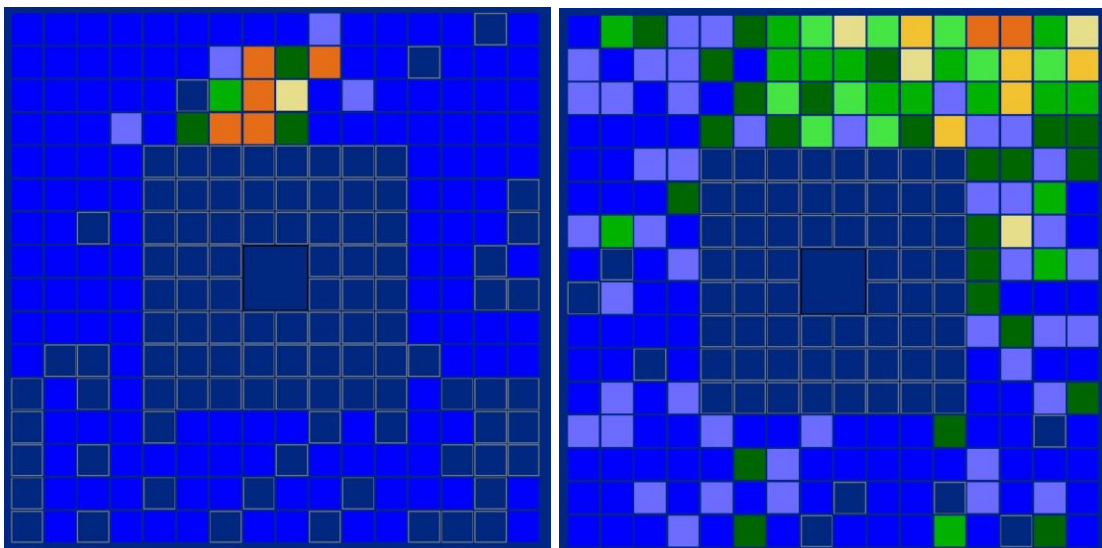


Fig. 3.6.9 *Two examples of μ -energy deposits in the KASCADE array*

3.7 ARRIVAL TIMES

In the measurement the ‘Arrival Times’ of each KASCADE array station represents the first time stamp of each station that has been hit by a charged particle corrected for cable delays and electronic effects. Basically the same applies in simulations but no further corrections are necessary. The first signals of each station represent the shower front and are used to determine the shower direction. The values of the arrival times are taken only from the e/γ –detectors.

A detector station that did not provide any time information was treated as ‘silent station’. Only arrival times and station IDs for non-silent stations are included in the data sets.

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.

Note: in chapter 7.2 are examples on how to handle the quantity ‘Arrival Times’

Thus, you will always be supplied with the following data sets:

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

3.7.1 NUMBER OF DETECTOR STATIONS WITH VALID ARRIVAL TIMES (ARRIVALN)

The range of **ArrivalN** is between about 5 and 252. The distribution is shown in fig. 3.7.1.

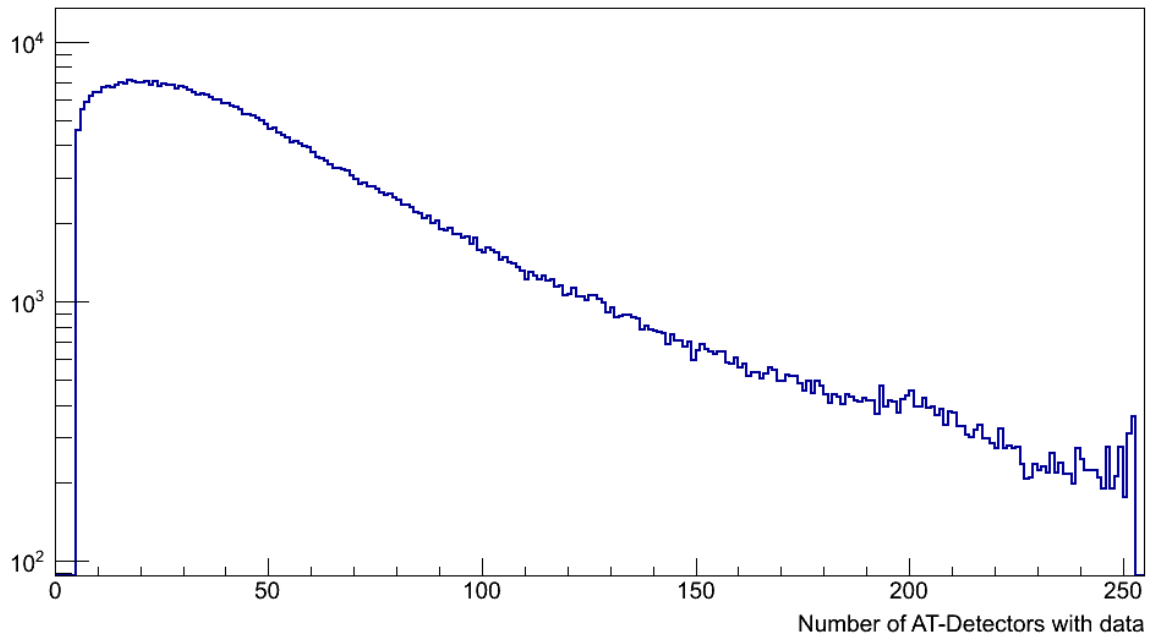


Fig. 3.7.1. *Distribution of the true number of detector stations with 'Arrival Time' information*

3.7.2 ARRIVAL TIMES PER STATION (ARRIVAL)

The arrival times are given with a resolution of 1ns/bin. Fig 3.7.2 shows the 'arrival time'–distribution. In the measurements the values of the arrival times can as well 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. In simulations only positive values are possible for KASCADE because the first time stamp is always taken as trigger signal at time '0 ns' or '1 ns'. This is the reason for the sharp peak at the beginning of the spectrum. At higher Energies there will be no significant change in the shape of the spectrum compared to the measurements as indicated in the red curve of fig. 3.7.2 where a cut as been applied on $N_e > 50000$.

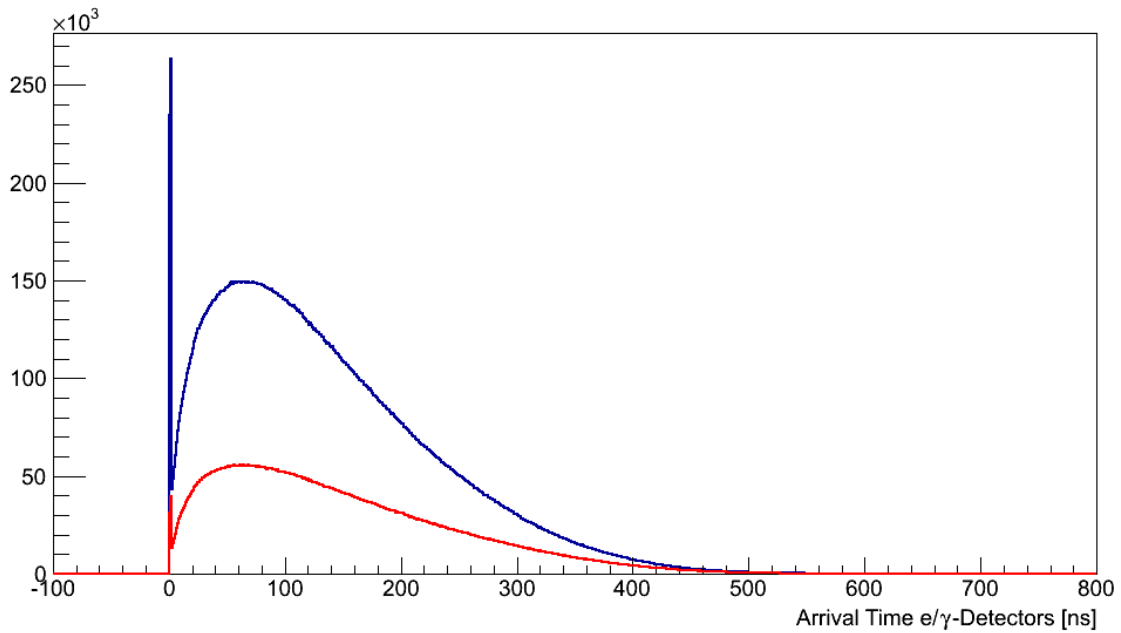


Fig. 3.7.2. *Arrival time distribution; no N_e cuts (blue); $N_e > 50000$ (red)*

3.7.3 STATION ID (ARRIVALS)

The station ID (same as in 3.6.1.4) 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 7.3 and Appendix A.

Fig 3.7.3 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. 3.6.4).

Note: This value is always shipped with 'Arrival Times' Quantity in the root files.

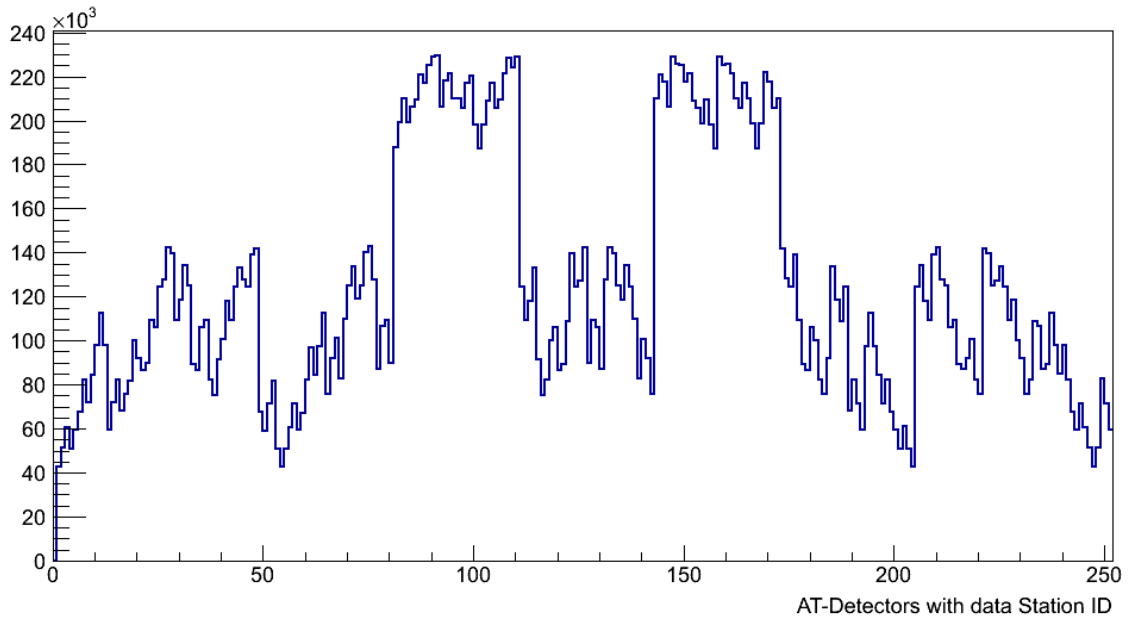


Fig. 3.7.3. *Distribution of station IDs for e/gamma-detector stations with valid Arrival Times*

3.7.4 EXAMPLE

As an example for the arrival time in the KASCADE array the **Arrival** distribution of two events is shown fig 3.7.4. The warmer the colour the bigger the time difference which usually corresponds to larger zenith angles. In the left example the shower is coming roughly from Az~220°, in the right example from Az~320°.

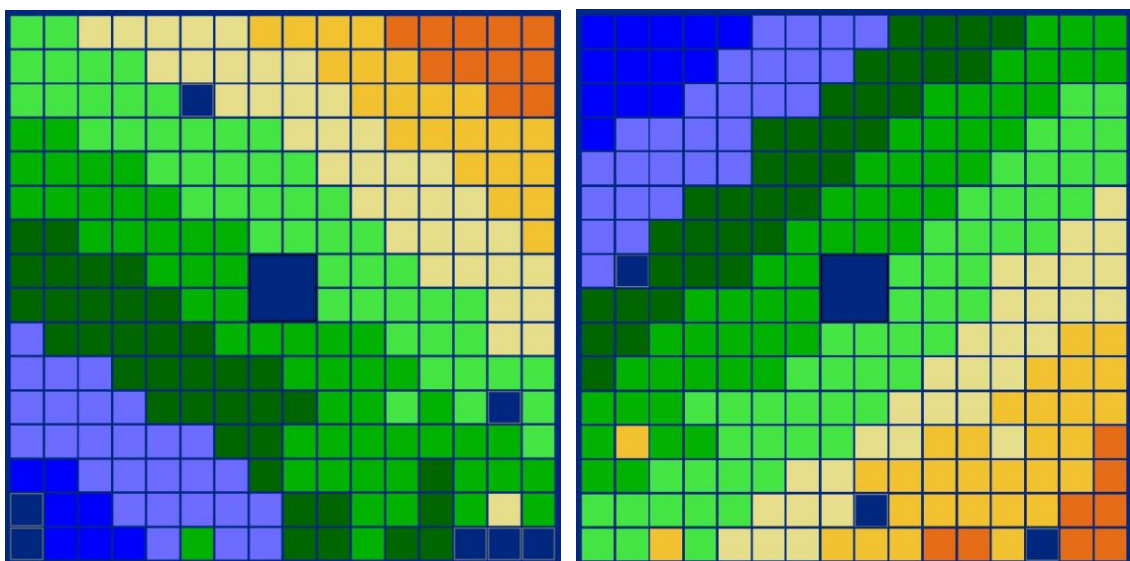


Fig. 3.7.4 *Two example of an arrival time distributions of the e/gamma-detectors in KASCADE*

3.8 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.

While the run number is a rather random number for simulations, the Event Number starts at '1' with each run and is increased with every simulated shower.

4 SIMULATED CALORIMETER DATA IN KCDC

The main component of the KASCADE Central Detector is an Iron-Sampling-Calorimeter $16 \times 20 \text{ m}^2$ in size. The hadrons and their interactions are important for the understanding of the shower development within the atmosphere. The parameters reconstructed from the calorimeter measurements and published in KCDC are the number of reconstructed hadrons and their energy sum.

CALORIMETER Quantity	Description	Unit	ID
Reconstructed Data			
Hadron Number	reconstructed number of Hadrons (fit)	<i>(number of)</i>	<i>Nhad</i>
Hadron Energy Sum	Sum Energy of all hadrons reconstructed	<i>(eV)</i>	<i>Ehad</i>

Fig. 4.1 shows the distribution of the simulated shower cores. In simulations every shower has been thrown once on the calorimeter, randomly distributed on an area of $23 \times 20 \text{ m}^2$ (dashed line in fig. 4.1) around the centre of the active area of the calorimeter (solid red line). The calorimeter is shifted by 5.19m to the north compared to the centre of KASCADE.

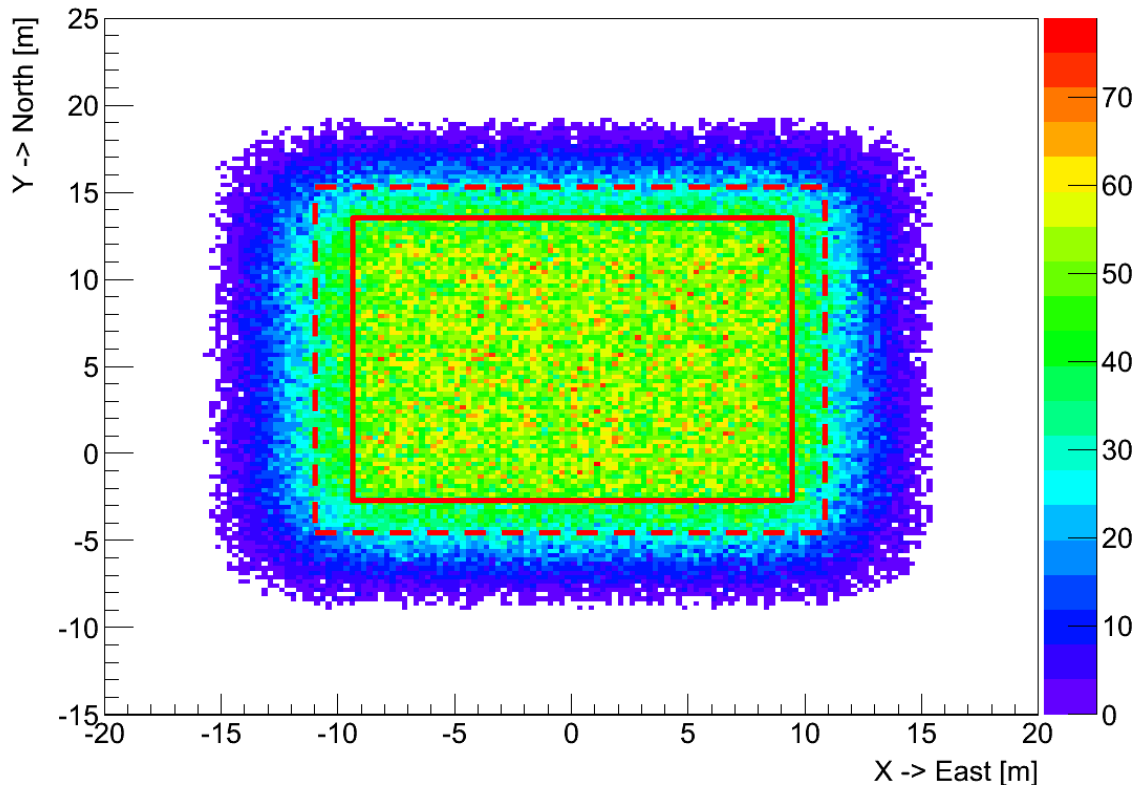


Fig. 4.1 *Distribution of shower cores thrown on the central hadron calorimeter without any cuts*

4.1 HADRON NUMBER

Due to the fine lateral segmentation and the read-out of the calorimeter in more than 40.000 electronic channels, hadrons in the energy range $20\text{GeV} < E_{\text{had}} < 25\text{TeV}$ can be measured. They can be separated from each other when the distance of their shower axis is above 40 cm. The spatial resolution of the calorimeter is about 11 cm and the energy resolution is 30% for hadrons with 100 GeV decreasing to 15 % for $E_{\text{had}}=25\text{ TeV}$. The analysis algorithm allows reconstructing up to 500 separated tracks in a shower core.

Fig. 4.1.1 shows the distribution of the reconstructed numbers of hadrons.

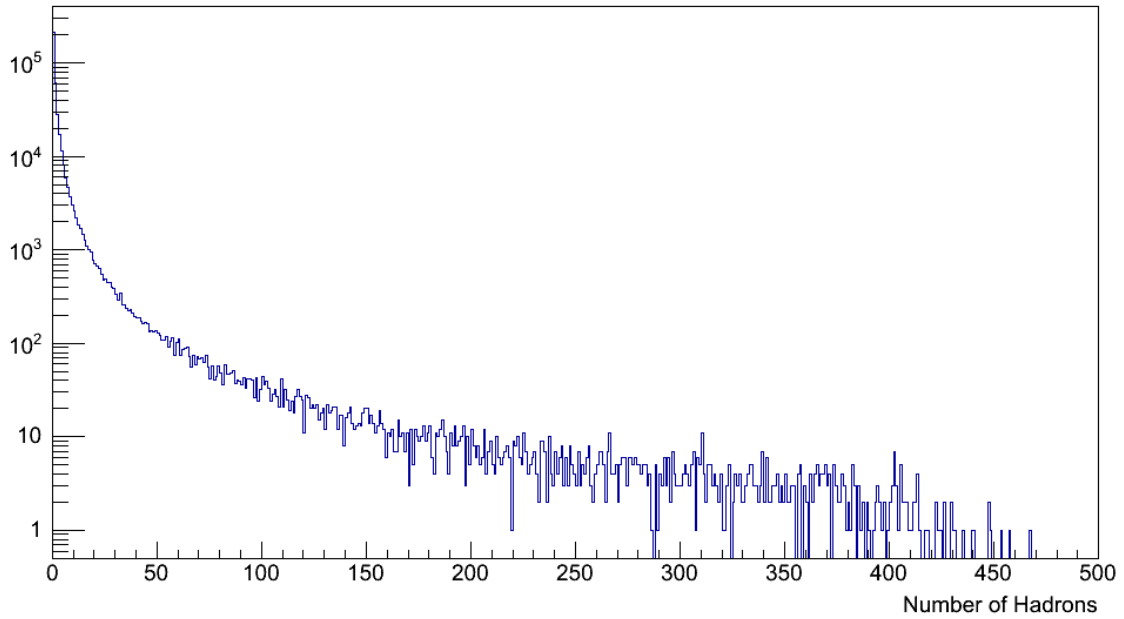


Fig. 4.1.1 *The distribution of true number of hadrons*

The range of values for simulations is described in the table below:

N_{had} Value	Description
0	No hadrons were reconstructed in the simulated shower
1 - 500	# hadrons reconstructed in the simulated shower

‘No hadrons were reconstructed’ does either mean that the hadron energy was below 20GeV, the shower core was well outside the active detector area or the reconstruction algorithm failed because too few active layers have been hit.

4.2 HADRON ENERGY

The value given here for the hadron energy is actually the sum of all hadron energies reconstructed in the hadron calorimeter in $\log_{10}[eV]$. Due to the fine segmentation of the calorimeter and the detection of the shower development in 9 active layers interspaced by iron absorbers, up to 500 hadrons can be separated and reconstructed individually. The range of the energy sum is between 20 GeV (lower threshold for one hadron) and about 10^7 GeV.

In fig. 4.2.1 the distribution of the energy sum of all reconstructed hadrons per event for all events reconstructed is given.

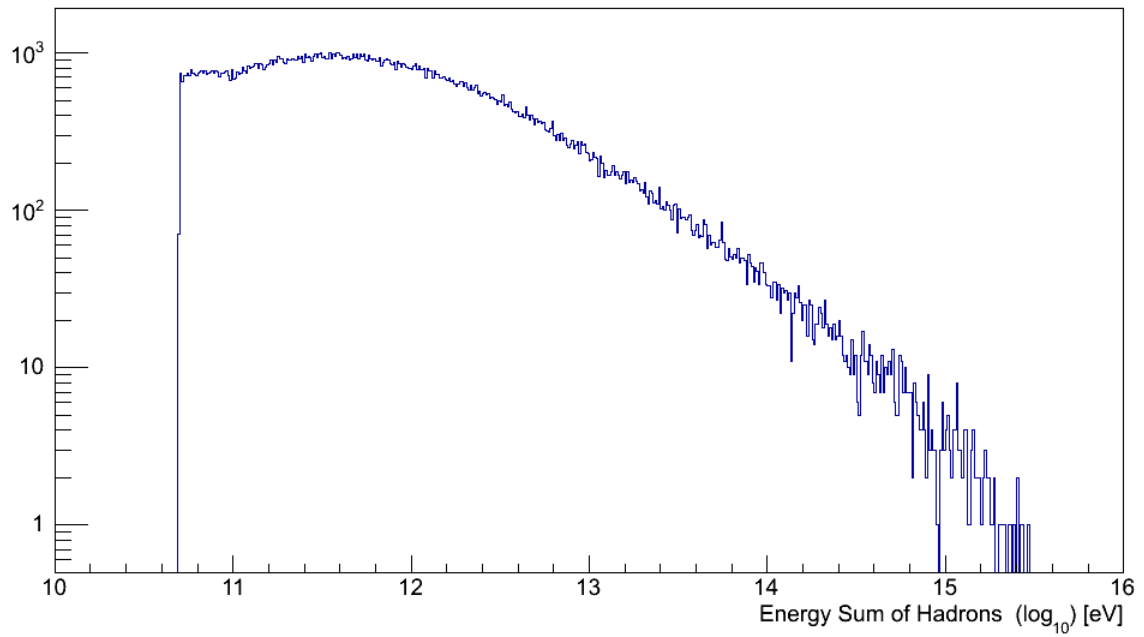


Fig. 4.2.1 *The distribution of the energy sum of all of reconstructed hadrons*

The range of valid values is described in the table below:

E_{had} Value	Description
0	No hadrons were reconstructed in the simulated shower
10 - 16	Energy sum in $\log_{10}[\text{eV}]$ for all simulated and reconstructed hadrons

5 SIMULATED GRANDE DATA IN KCDC

The simulated air showers in the KASCADE-Grande array (GRANDE) are analysed using the reconstruction program KRETA (*Kascade Reconstruction for ExTensive Air showers*).

From the observables obtained in the analysis, we choose 9 to be published in KCDC, two of which are data arrays holding information on energy deposit and arrival time in each of the 37 GRANDE detector stations.

If not stated otherwise, the GRANDE quantities are reconstructed in the same way as the KASCADE array quantities. Merely the parameters for the fits are different. Described here are only the GRANDE simulated data, event information are explained in detail in chapter 3.

GRANDE Quantity	Description	Unit	ID
Reconstructed Data			
Core Position Xc	location of the reconstructed GRANDE shower core X-position	m	Xc
Core Position Yc	location of the reconstructed GRANDE shower core Y-position	m	Yc
Zenith Angle	zenith angle reconstructed by GRANDE with respect to the vertical	° (<i>degree</i>)	Ze
Azimuth Angle	azimuth angle reconstructed by GRANDE	° (<i>degree</i>)	Az
Number of Charged Particles	number of charged particles reconstructed by GRANDE	(<i>number of</i>)	Nch
Muon Number	number of Muons (fit) reconstructed by GRANDE	(<i>number of</i>)	Nmu
Age	GRANDE Shower shape parameter		Age
Energy Deposits	charged energy deposit per GRANDE detector station	(<i>MeV</i>)	GDeposit
Arrival Times	Arrival Times per GRANDE detector station	(<i>ns</i>)	GArrival

In simulations, every shower has been thrown 10 times on GRANDE, randomly distributed on an area of 750x790m² as shown in fig 5.1. Displayed as well are the GRANDE detector stations.

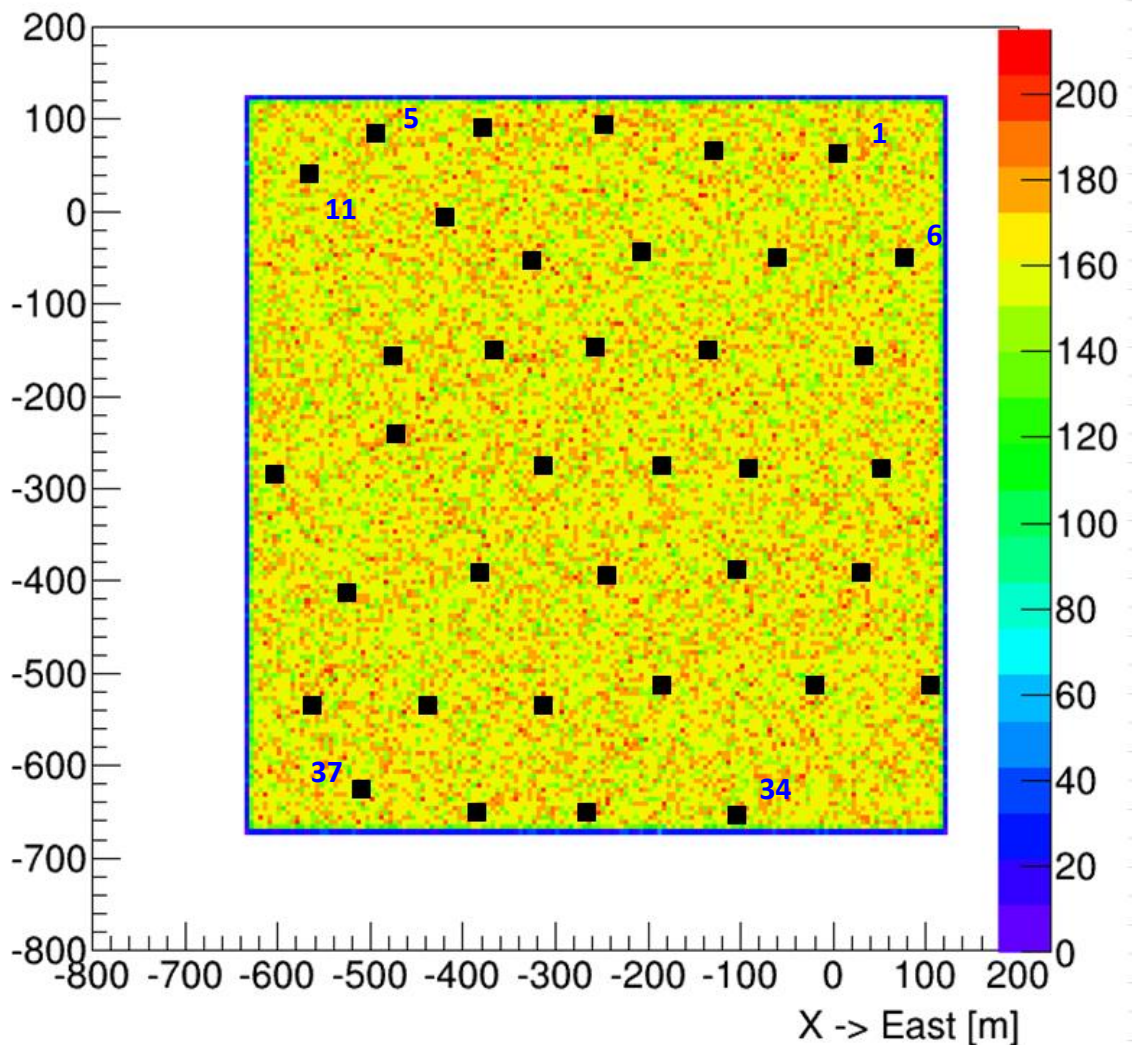


Fig. 5.1 *Distribution of the shower cores of all simulated showers in GRANDE without any cuts. Shown also are the GRANDE detector stations.*

The plots shown in this chapter are only examples, mostly based on a subsample of the simulated data sets and only for one simulation model (QGSjet-II-04). So, applying user cuts in your own analysis can change these spectra drastically.

For GRANDE we do not give an estimation of the energy of the primary particle because this value strongly depends on the simulation model and the cuts applied. As a rough estimator one can use

$$\lg(E_{\text{Grande}}/\text{eV}) = (1.402 + 0.9266 * \lg(N_{\text{ch}})) + 9.0$$

for Grande energies given in log10/eV.

5.1 NUMBER OF CHARGED PARTICLES AND NUMBER OF MUONS IN GRANDE (N_{CH}, N_{MU})

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 in the shower, i.e. the shower size are reconstructed. The reconstruction is performed similar to KASCADE but with different parameters. The number of Muons (N_μ) is taken from the KASCADE detector stations participating in the respective event with a simplified method. As there are normally only few KASCADE 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.

Figures 5.1.1 shows the N_{ch} spectrum of the simulated showers reconstructed with KRETA (red) and the true N_{ch} spectrum (black). The quality cut is at N_{ch}=11111. In fig 5.1.2 the number of true N_{ch} from CORSIKA is plotted against the number of GRANDE reconstructed charged particles. The reconstructed N_{ch} is the sum of the reconstructed N_e and N_μ. Therefore, when we compare to the true number, the true N_{ch} is the sum of true N_e (TrNe) and N_μ (TrNm) from the air shower simulations, which is in excellent agreement with the reconstructed number of charged particles.

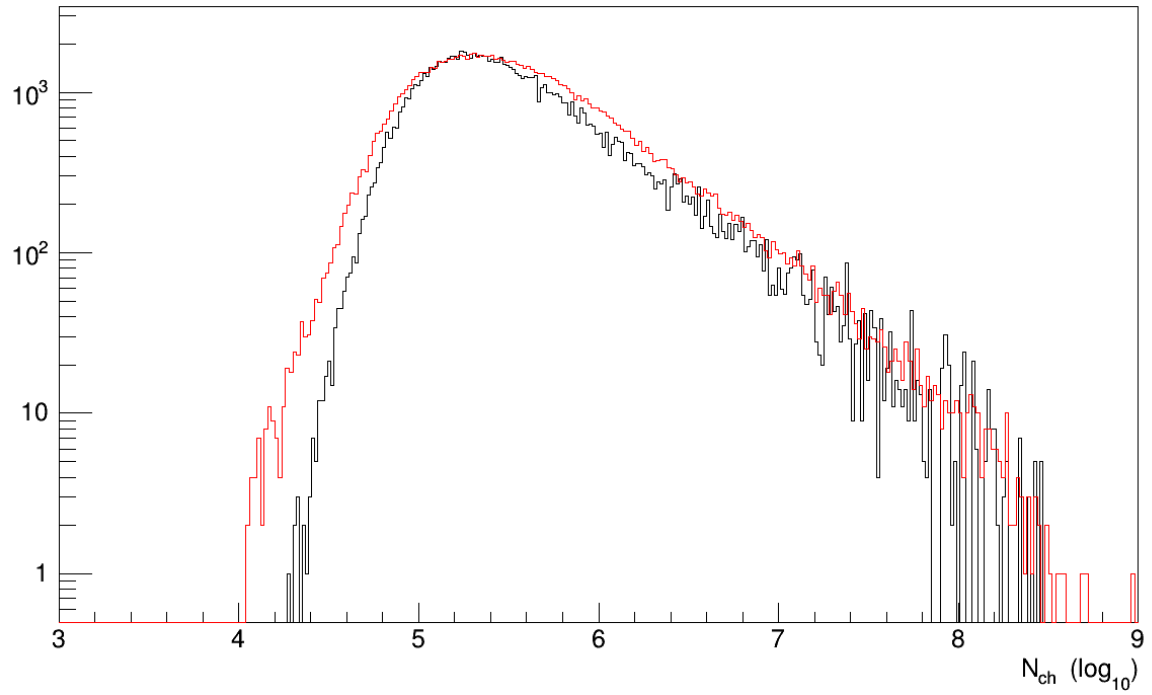


Fig. 5.1.1 *The spectrum of the true number of charged particles in GRANDE*

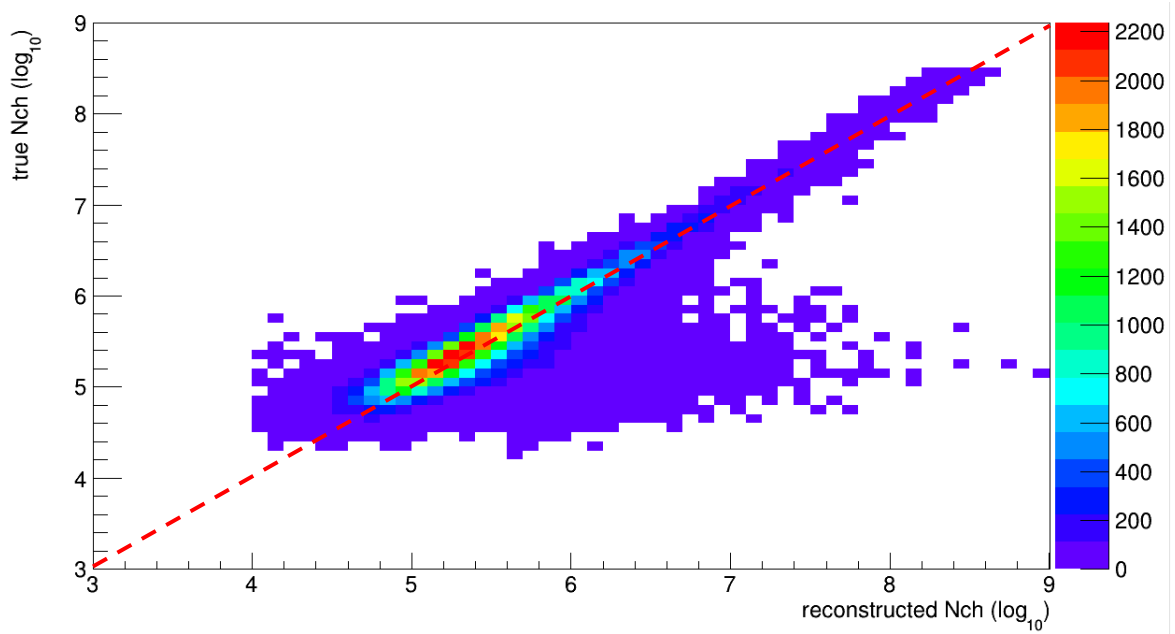


Fig. 5.1.2 *N_{ch} spectrum; true N_{ch} vs N_{ch} after reconstruction. The dashed red line denotes the expected value from the sum of N_e and N_μ .*

Fig. 5.1.3 shows the N_μ spectrum of the simulated proton showers reconstructed with KRETA (red) and the true N_μ spectrum (black). The quality cut is at $N_\mu=1500$. The good agreement of the reconstructed number of muons with the real number is shown in fig. 5.1.4

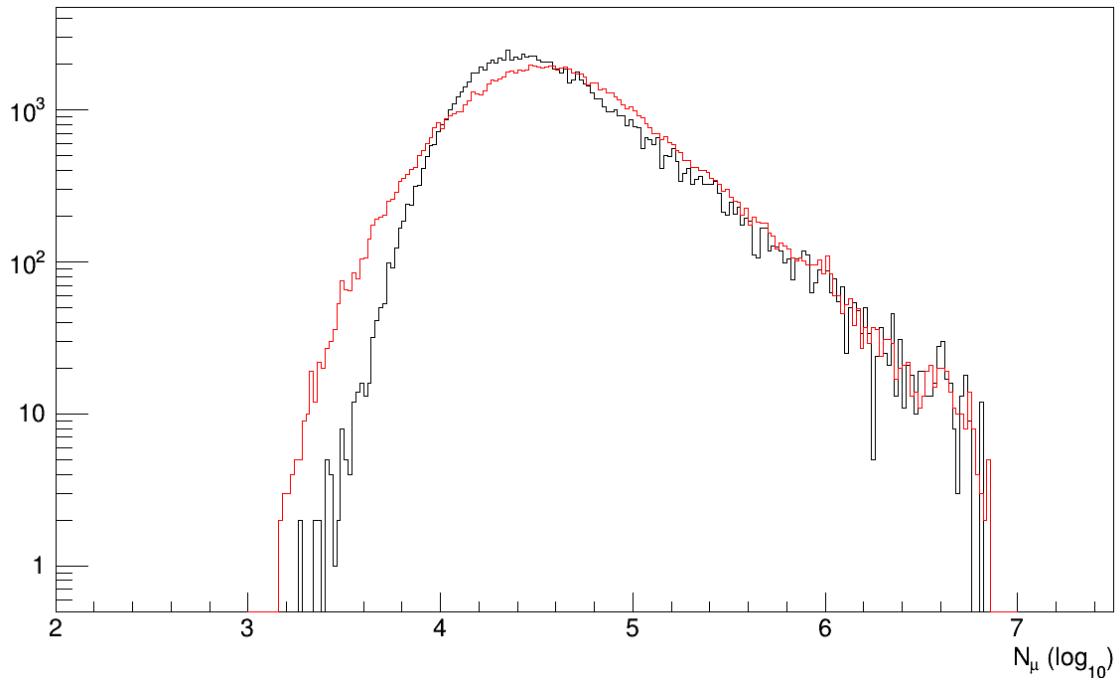


Fig. 5.1.3 *The spectrum of the true number of muons from GRANDE*

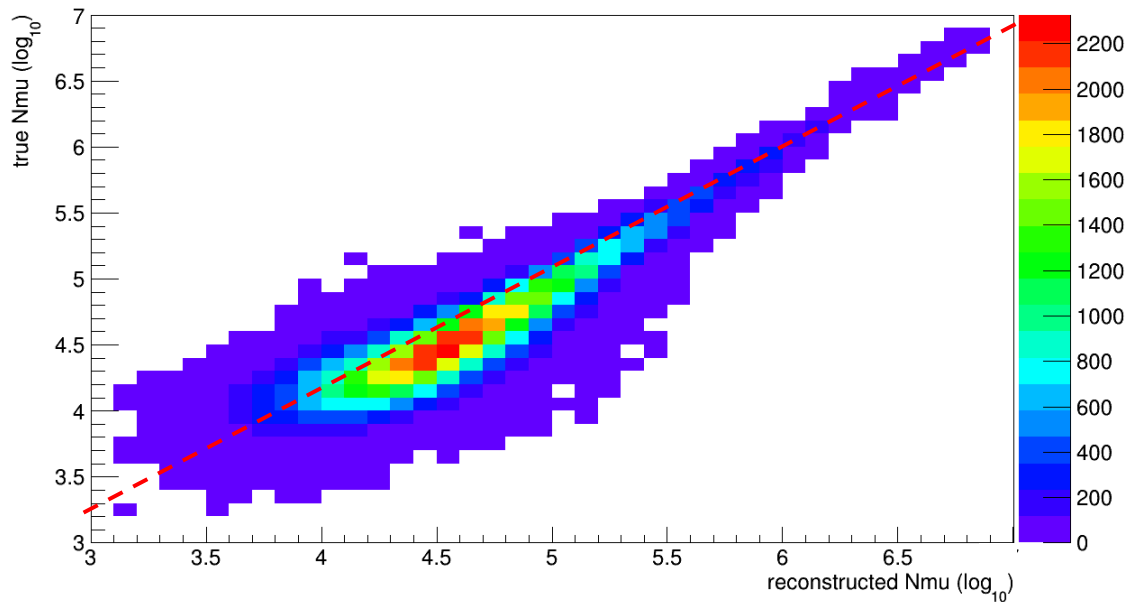


Fig. 5.1.4 *N_μ spectrum; true N_μ vs N_μ after GRANDE reconstruction. The dashed red line denotes the expected value*

5.2 GRANDE AGE (AGE)

Like in KASCADE, the GRANDE age parameter describes the steepness of the lateral electron density distribution. Within this function, the age parameter values are limited theoretically to a range from -0.385 to 1.485. Common shower values however should not be negative. Lower values describe steeper lateral distributions.

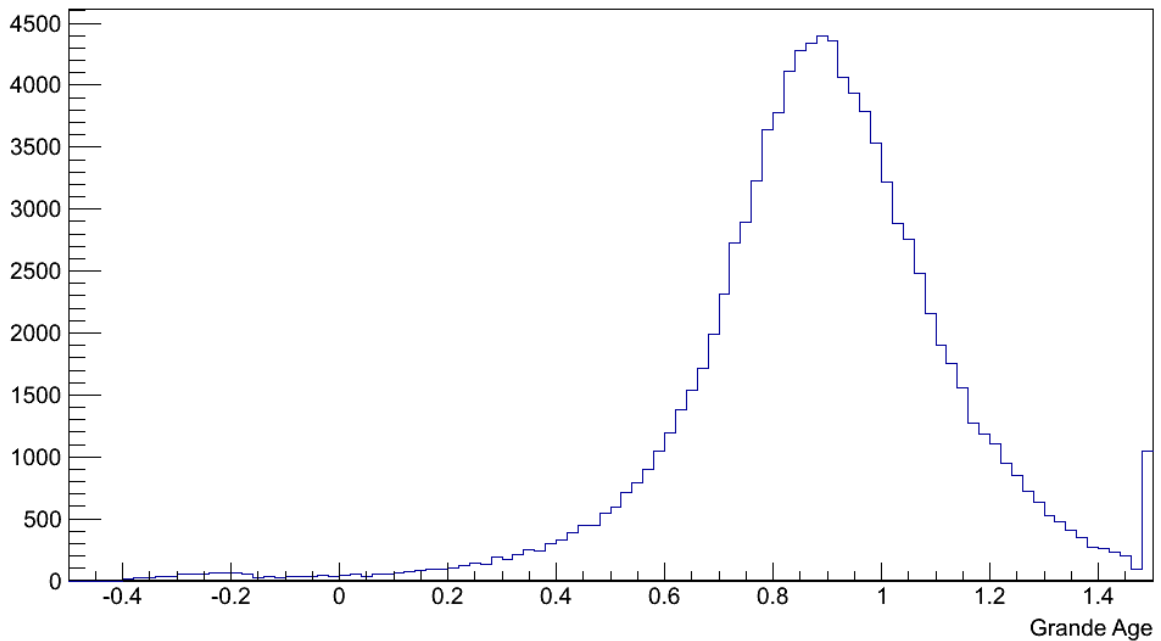


Fig. 5.2.1 *The GRANDE Age distribution for reconstructed showers*

5.3 GRANDE SHOWER CORE POSITION (X_C , Y_C)

The GRANDE shower core position is the reconstructed location of the shower centre at GRANDE level (same as KASCADE level) derived from the energy deposits of each of the 37 detector stations of one event. The unit of the core position is [m].

For the reconstruction of the GRANDE core position like at the KASCADE array basically the energy deposits in every detector station are taken. The core can be determined to a precision of about 10m.

Simulated GRANDE Data in KCDC

In figs 5.3.1. and 5.3.2 the distributions of the X- and Y-core positions are shown. The structure in the Y-core position distribution is caused by the fact that in the y-projection the Grande stations are nearly aligned (see also figs 5.1 & 5.3.3).

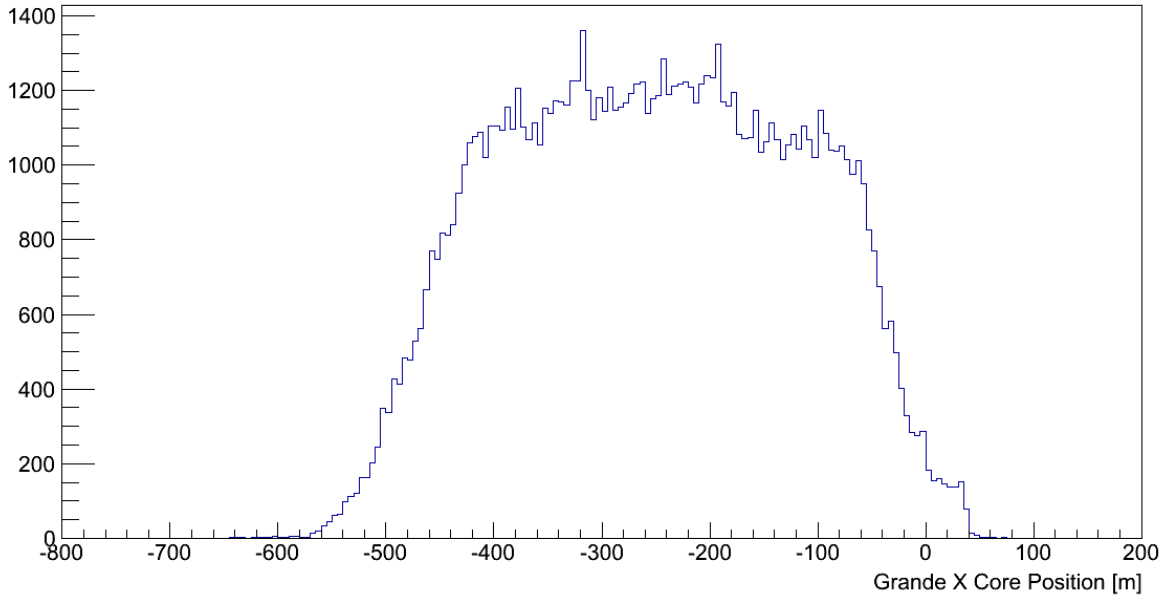


Fig. 5.3.1 *X-core position of reconstructed proton showers in GRANDE*

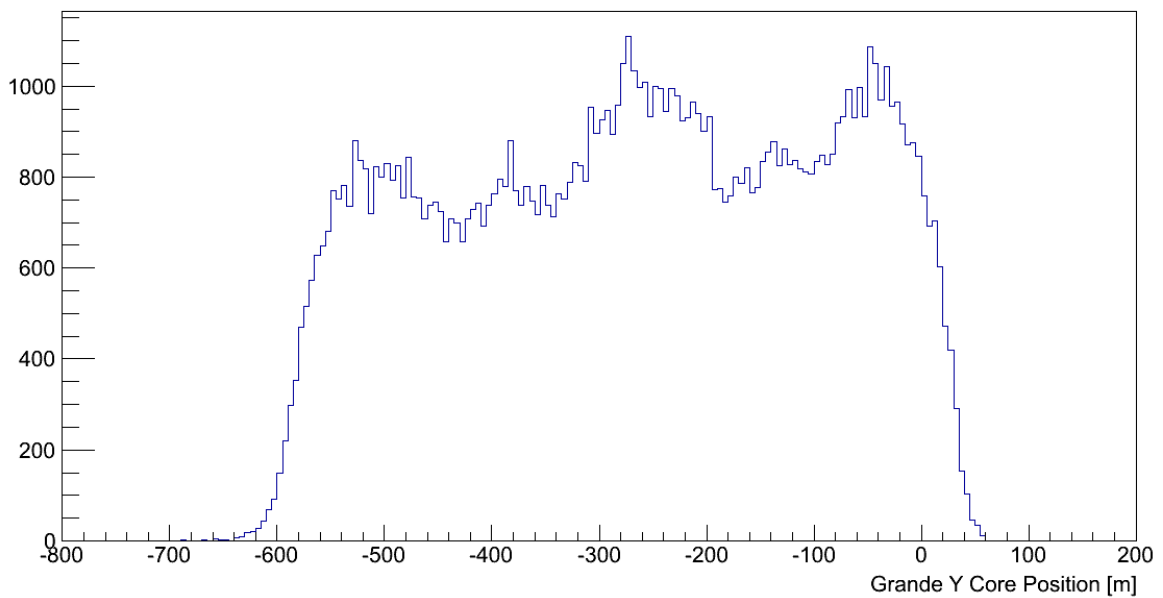


Fig. 5.3.2 *y-core position of reconstructed proton showers in GRANDE*

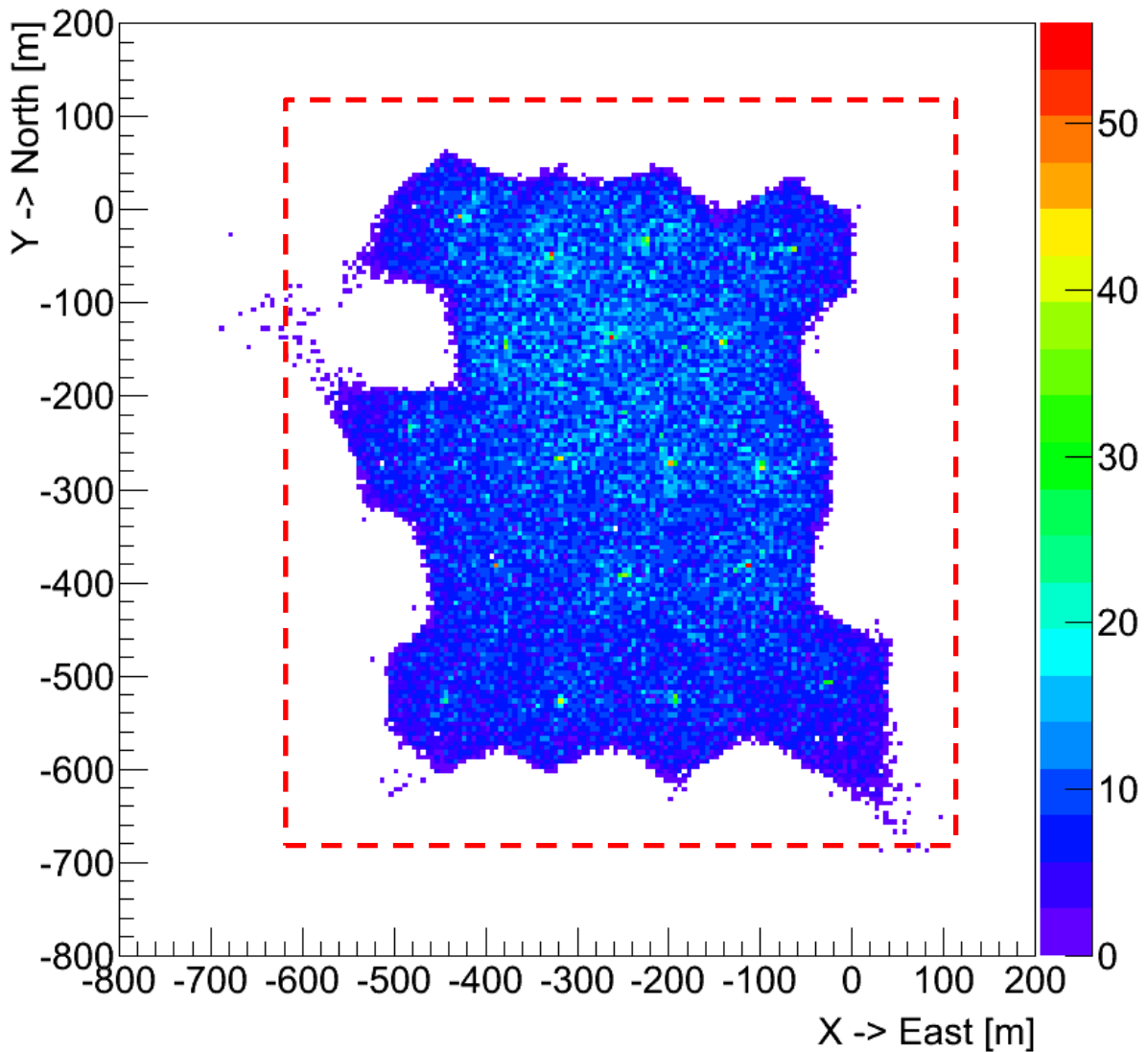


Fig. 5.3.3 *Shower core distribution with GRANDE array detector stations with station cut on data*

The distribution of the shower core is plotted in the fig. 5.3.3. Extensive air showers with a core position outside the detector area or close to the border have a great probability for being incorrectly reconstructed. Therefore showers where the maximum energy deposit was recorded in a border station of GRANDE are excluded. This cut is responsible for the ‘strange’ shape of the shower core distribution.

The quality of the reconstruction is shown in figs 5.3.4 to 5.3.6. In figs. 5.3.4 & 5.3.5 the X- and Y-positions are displayed versus the true positions of the simulated shower core, while in fig. 5.3.6 the absolute deviation of the reconstructed shower core position is shown. The true core

position is derived from CRES detector simulations, where the shower core is randomly distributed over a pre-defined detector area (see also fig 5.1).

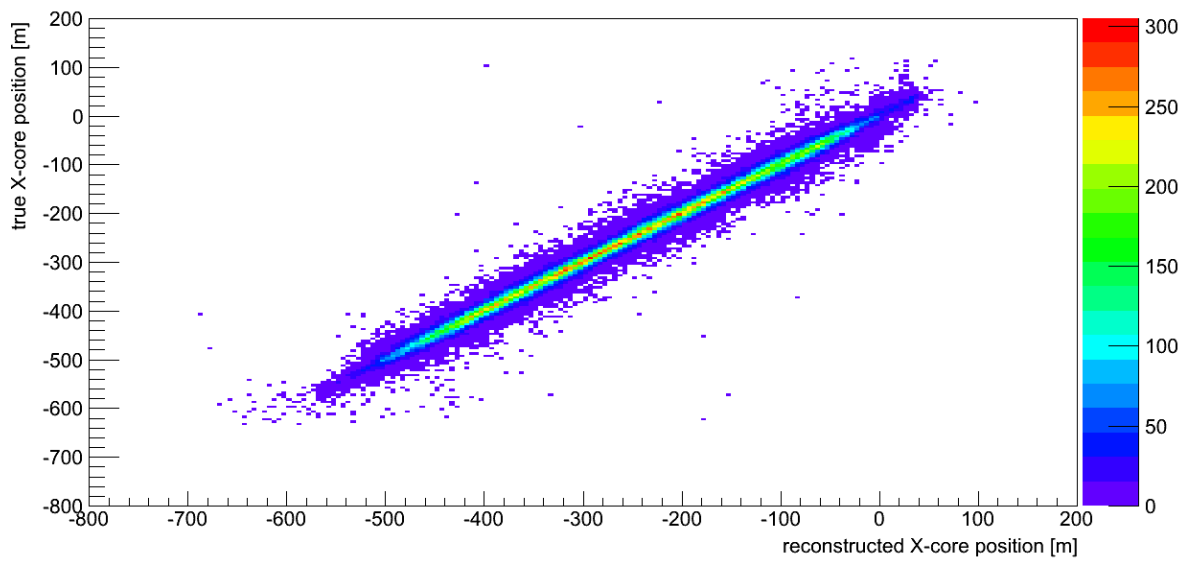


Fig. 5.3.4 *True X-shower core position vs reconstructed X-shower core position for proton induced showers in GRANDE*

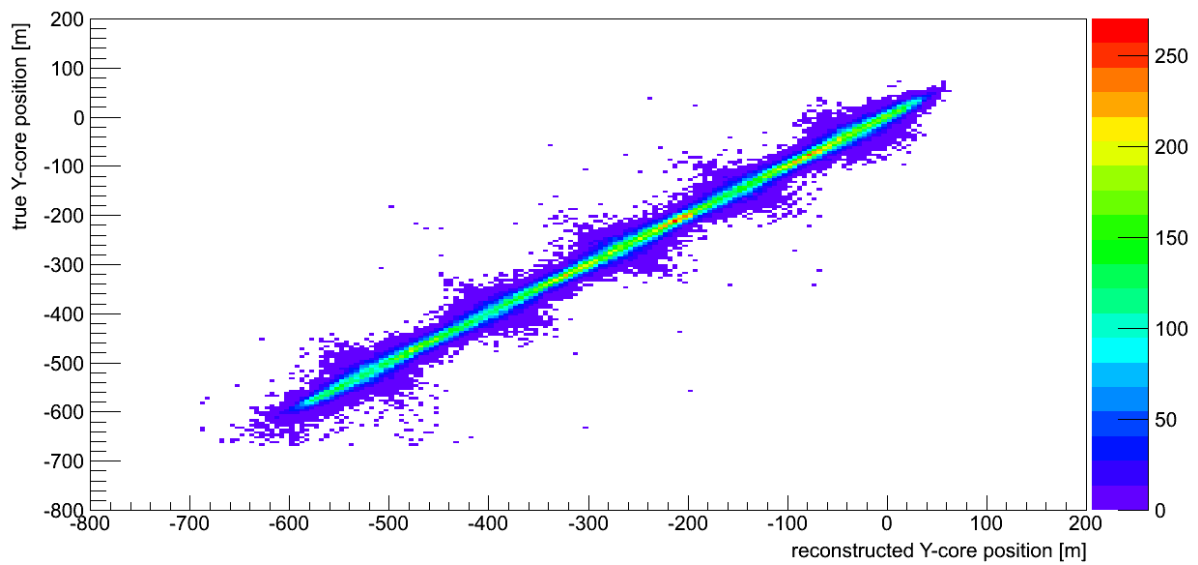


Fig. 5.3.5 *True Y-shower core position vs reconstructed Y-shower core position for proton induced showers in GRANDE*

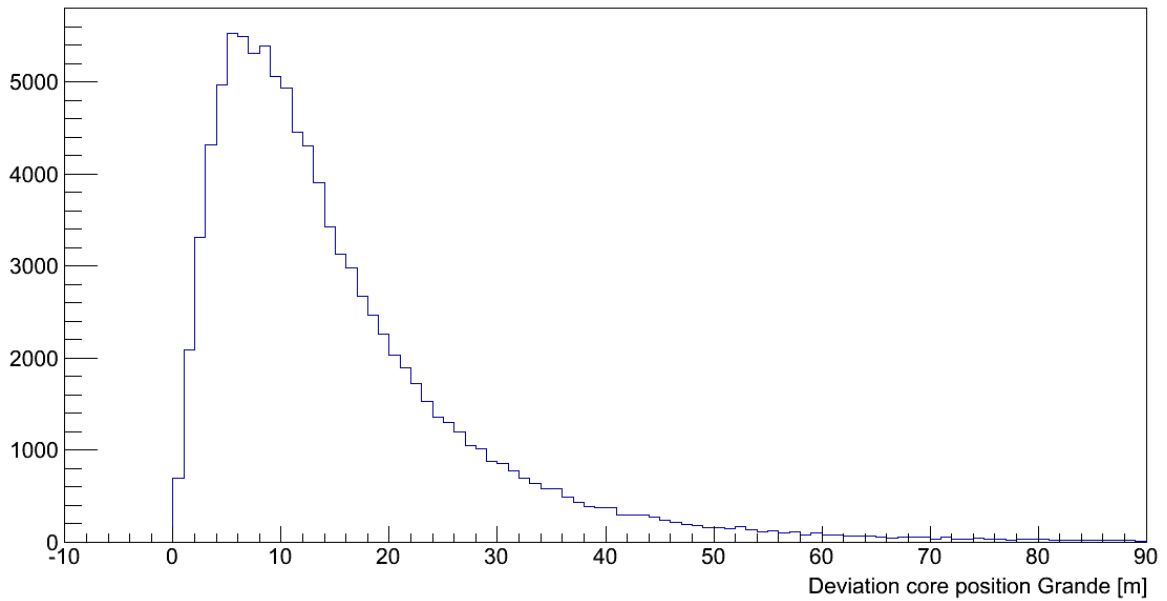


Fig. 5.3.6 *Absolute deviation of the shower core position between true and reconstructed core positions in GRANDE*

5.4 GRANDE SHOWER DIRECTION (ZE, Az)

In GRANDE, the shower directions are determined by evaluating the arrival times of the first particle in each detector station. To increase the accuracy, the energy deposits are taken into account when the direction of the shower disk is calculated.

Like in KASCADE the GRANDE zenith angle is measured against the vertical direction, which means that $\theta=0^\circ$ is pointing upwards and 90° denotes a horizontal shower. The azimuth is accordingly defined as an angle measured clockwise starting in northern direction (90° is east). The orientation of the GRANDE Array has an offset of about $+15^\circ$ against the real northern. This offset is corrected for in the data analysis. The unit of the azimuth and zenith angle is $[\circ]$.

In figure 5.4.1 the distributions of the GRANDE azimuth angle is shown. Fig 5.4.2. shows the distribution of the zenith angle.

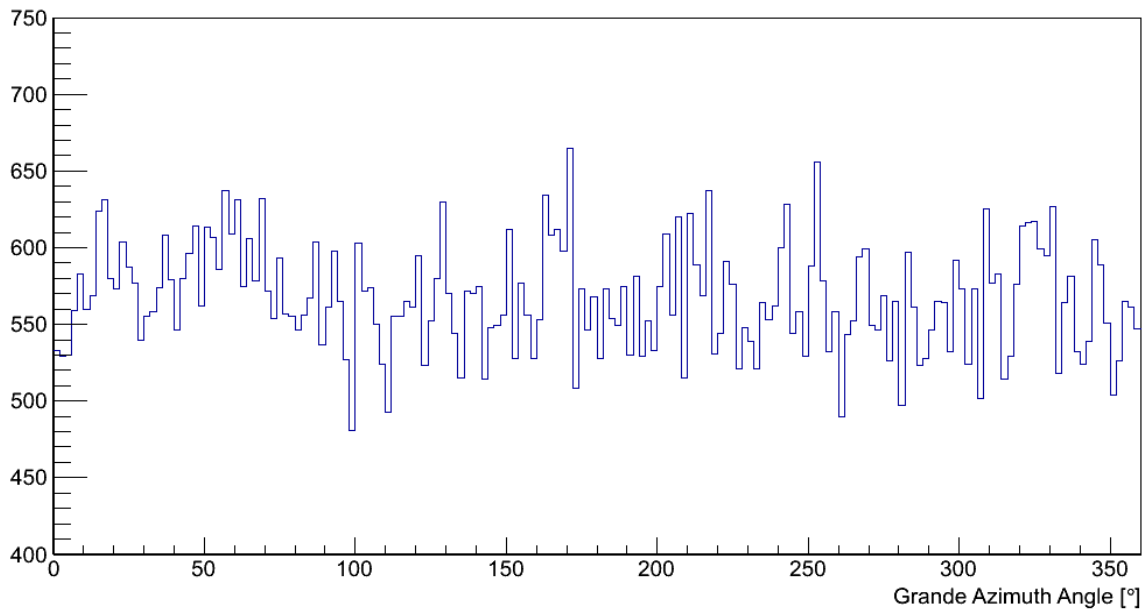


Fig. 5.4.1 *The distribution of the reconstructed GRANDE azimuth angle*

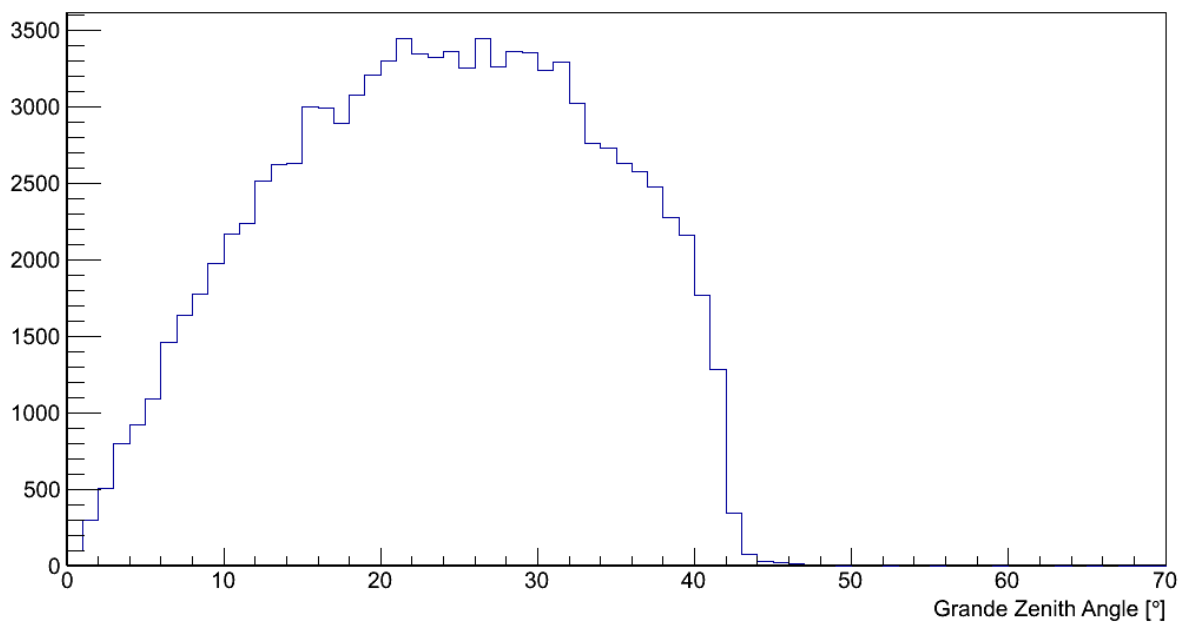


Fig. 5.4.2 *The distribution of the reconstructed GRANDE zenith angle*

5.5 GRANDE ENERGY DEPOSITS PER STATION (GDEPOSIT)

The energy deposits of each single detector station are simulated and reconstructed in the 37 GRANDE detectors.

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

Note: in chapter 7.2 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. For simulations all stations are always active which implies that the number of detector stations with valid energy deposit information (**GDepositN**) is always 37.

Thus, 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]

5.5.1 NUMBER OF ACTIVE GRANDE DETECTOR STATIONS (GDEPOSITN)

The number of active GRANDE detector stations stored in **GDepositN** is always 37.

Note: This value is always shipped with 'Grande Energy Deposit' Quantity in the root files.

5.5.2 NUMBER OF ACTIVE GRANDE DETECTOR STATIONS WITH HITS

The distribution of the number of GRANDE detectors with $GDeposit > 0$ is given in fig 5.5.1.

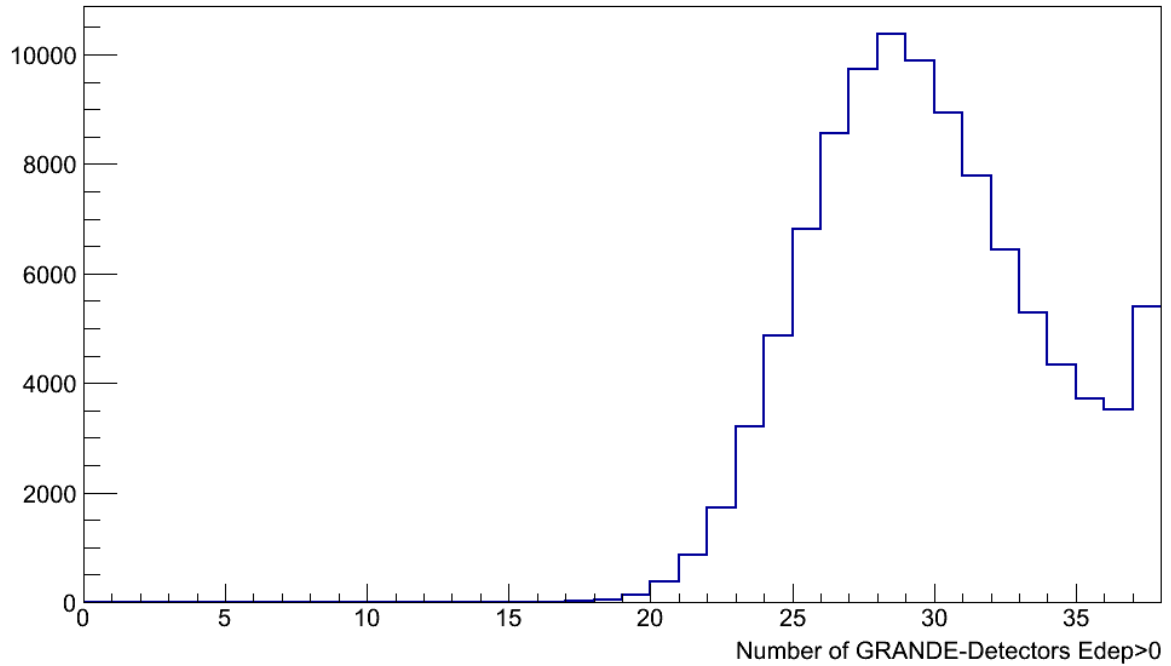


Fig. 5.5.1 *Distribution of the true number of GRANDE detector stations with hits*

5.5.3 GRANDE ENERGY DEPOSIT FOR EACH DETECTOR STATION (GDEPOSIT)

The Energy deposits are directly taken from the simulations for each GRANDE detector station. **GDeposit** values are given in MeV. In fig 5.5.2 the energy deposits for simulated proton induced showers are plotted. The overflow cut is set to 90 GeV.

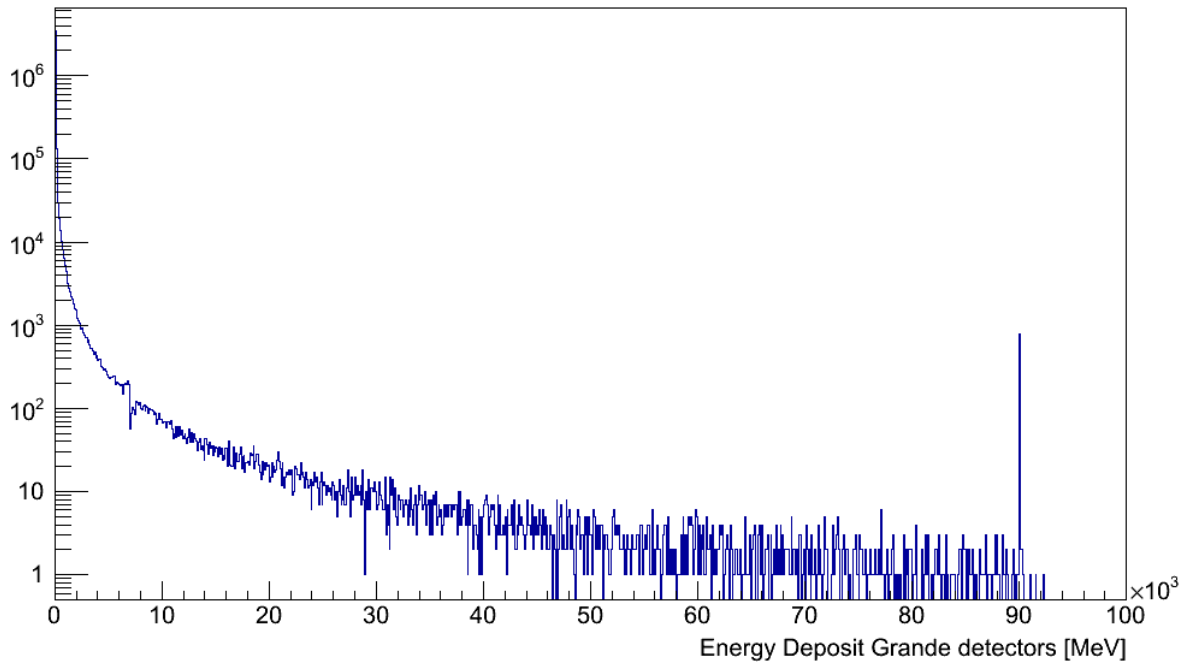


Fig. 5.5.2 *Distribution of the GRANDE Energy Deposits of all active stations*

5.5.4 GRANDE 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 7.4 and Appendix B.

Fig 5.5.3 shows the distribution of station IDs of the active GRANDE detector stations. The distribution is flat for simulations because we do not include inactive stations in our detector simulations. Stations with energy deposits above 90 GeV are active too, the deposits are not taken into account for analysis but are included in the data samples.

Note: This value is always shipped with 'Grande Energy Deposit' Quantity in the root files.

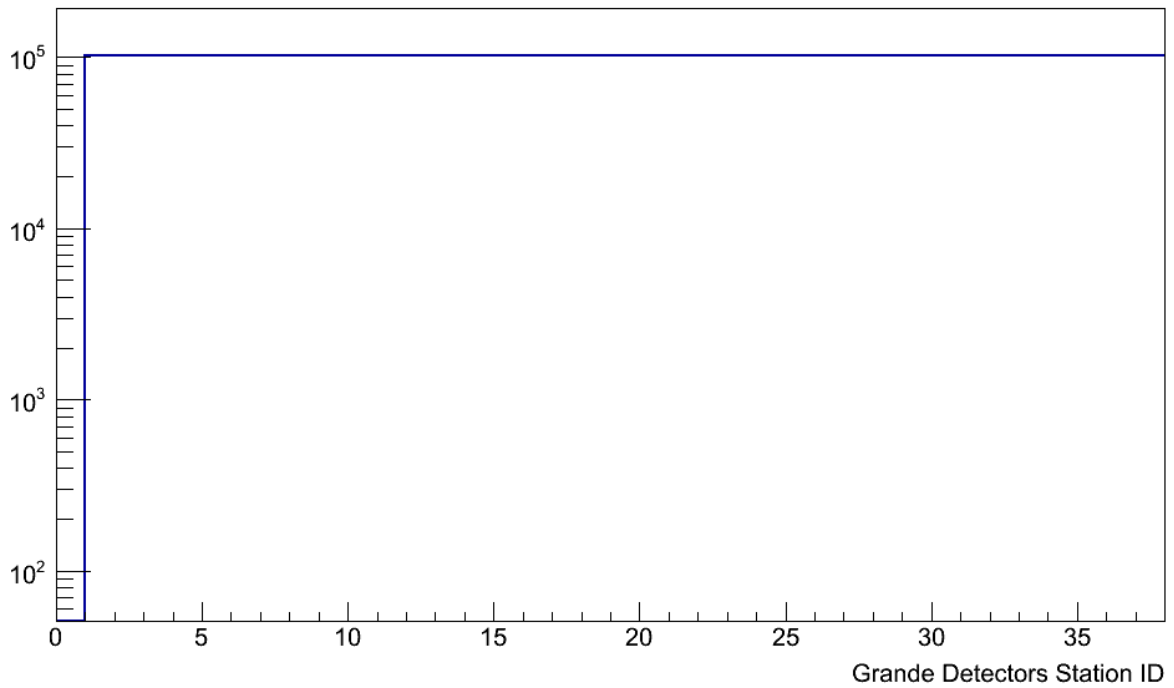


Fig. 5.5.3 *Distribution of station IDs for e/ γ -detector stations*

5.5.5 EXAMPLE

As an example for energy deposits in the GRANDE array the **GDeposit** distribution of two events is shown in fig. 5.5.4. The warmer the colour the higher the deposited energy in the 37 GRANDE detector stations.

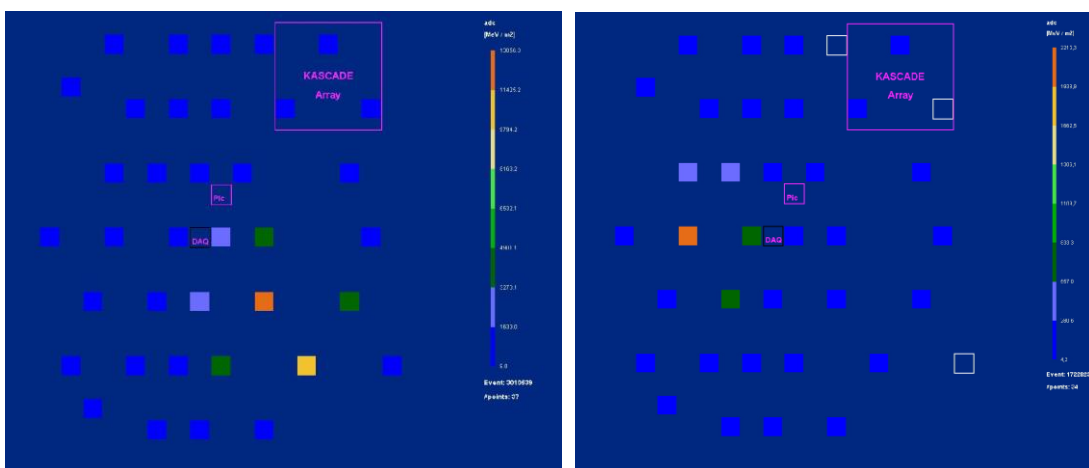


fig. 5.5.4 *Two examples of energy deposits in the GRANDE array*

5.6 ARRIVAL TIMES

In the measurement the '**Grande Arrival Times**' of each GRANDE array station represents the first time stamp of each station that has been hit by a charged particle corrected for cable delays and electronic effects. Basically the same applies in simulations but no further corrections are necessary. 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 that hit GRANDE.

A detector station, which did not provide any time information, was treated as 'silent station'. Only arrival times and station IDs for non-silent stations are included in the data sets.

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.

Note: in chapter 7.2 are examples on how to handle the quantity '**Grande Arrival Times**'

Thus, you will always be supplied with the following data sets:

GArrivalN	number of GRANDE detector stations with arrival times [1 ... 37]
GArrival	Arrival time in [ns] bins
GArrivals	detector station ID [1...37]

5.6.1 NUMBER OF GRANDE DETECTOR STATIONS WITH VALID ARRIVAL TIMES (GARRIVALN)

The distribution of **GArrivalN** is shown in fig. 5.6.1.

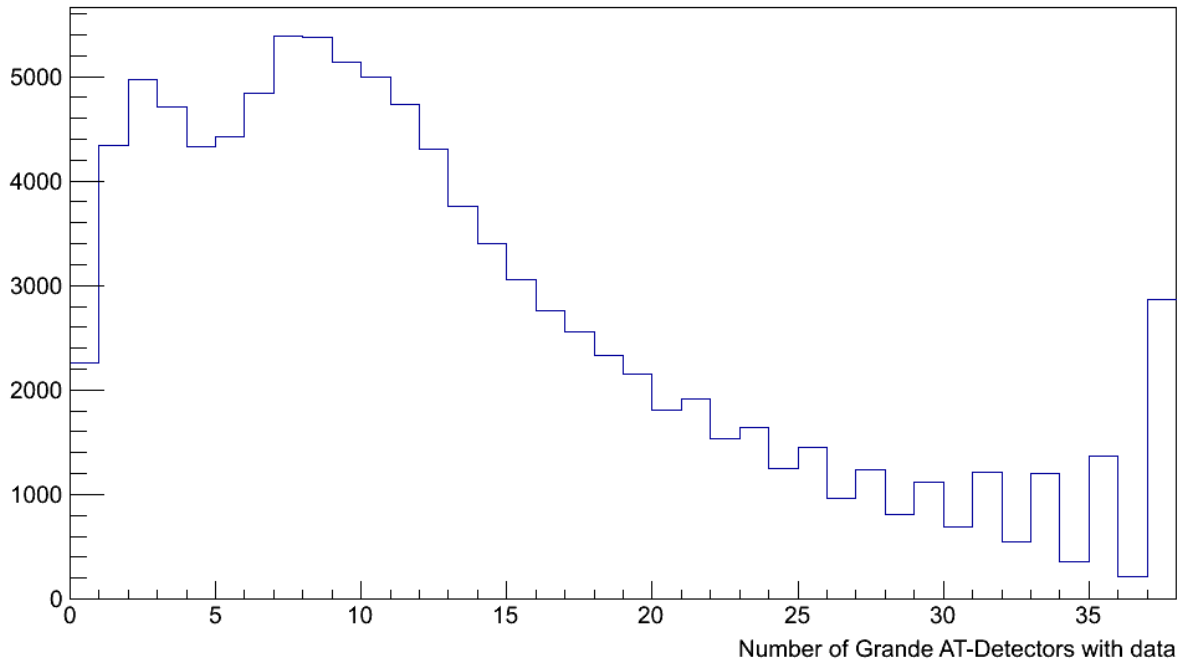


Fig. 5.6.1. *Distribution of the number of GRANDE detector stations with reconstructed 'Arrival Times' information*

5.6.2 ARRIVAL TIMES PER GRANDE STATION (GARRIVAL)

The '**GRANDE Arrival Times**' are given with a resolution of 1ns/bin. Fig 5.6.2 shows the 'Grande Arrival Time' distribution.

In the measurements the values of the '**GArrival**' can not be negative due to the fact that the delay for trigger coincidence is rather high because of the long distances between the Grande detectors. In simulations negative values are possible for GRANDE because the event time is taken from the first 7/7- coincidence and earlier time stamps in the stations within the respective trigger hexagon are possible.

This effect is illustrated by the red curve where only showers with a reconstructed zenith angle below 15° are plotted while the green curve denotes showers with zenith angles above 30°.

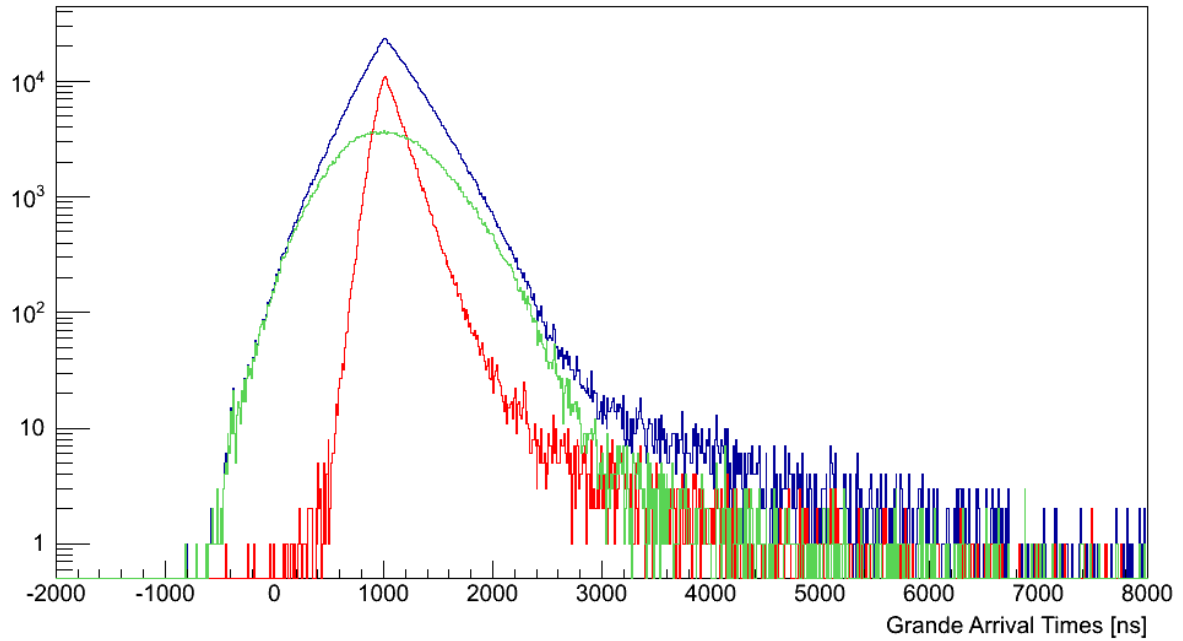


Fig. 5.6.2 *GRANDE Arrival time distribution; no cuts (blue); $Z_e < 15^\circ$ (red); $Z_e > 30^\circ$ (green):*

5.6.3 GRANDE STATION ID (GARRIVALS)

The GRAND station ID (same as 5.5.4) 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 7.4 and Appendix B. Fig 5.6.3 shows the distribution of station IDs of the GRANDE detector stations with AT information. The structure is mostly caused by the area cut for the effective area in the core position of the GRANDE showers.

Note: This value is always shipped with the ‘GRANDE Arrival Times’ in the root files.

Simulated GRANDE Data in KCDC

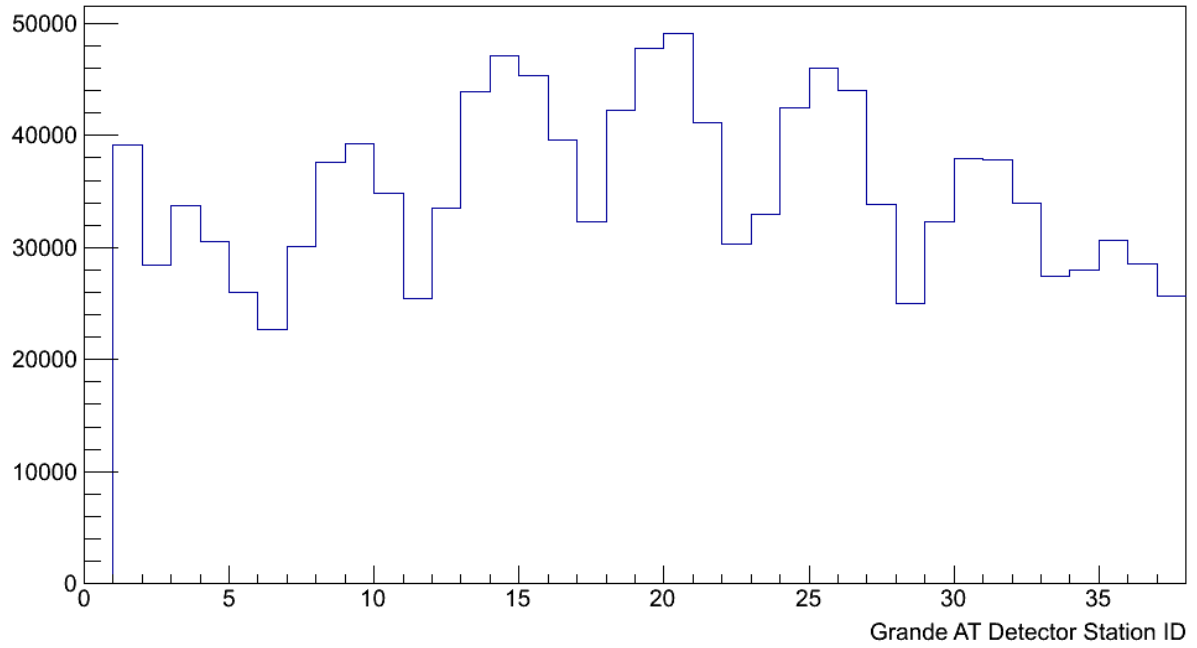


Fig. 5.6.3 *Distribution of station IDs for GRANDE detector stations with valid arrival times*

5.6.4 EXAMPLE

As an example for the arrival times in GRANDE the **GArrival** distribution of two events is shown in fig. 5.6.4. The warmer the colour the bigger the time difference which usually corresponds to larger zenith angles.

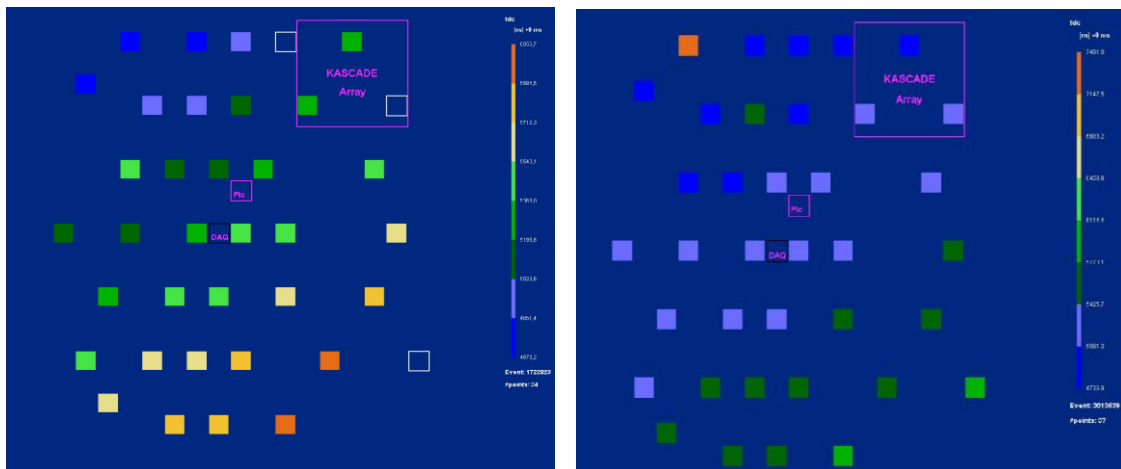


Fig. 5.6.4 *Two examples of arrival time distributions in GRANDE*

6 TRUE SHOWER SIMULATION DATA IN KCDC

The CORSIKA simulation package offers a variety of information describing the real shower development and the secondary particles at observation level. Some of these data like the primary particle initiating the shower or its energy are passed through the analysis steps of event simulation (CORSIKA), detector simulation (CRES) and data reconstruction (KRETA) and stored in the respective root trees.

From all available observables taken directly from the simulations we choose 10 to be published in KCDC called ‘Monte Carlo Information’.

All these numbers are true only for the observation level, latitude and longitude of KASCADE.

Monte Carlo Information			
True Energy	True Primary Energy inducing the shower	<i>eV</i>	<i>TrEP</i>
True Particle ID	True Primary Particle ID inducing the shower		<i>TrPP</i>
True X Core Position	True location of the simulated shower core x-position	<i>m</i>	<i>TrXc</i>
True Y Core Position	True location of the simulated shower core y-position	<i>m</i>	<i>TrYc</i>
True Zenith Angle	True simulated zenith angle with respect to the vertical	<i>° (degree)</i>	<i>TrZe</i>
True Azimuth Angle	True simulated azimuth angle with respect to north	<i>° (degree)</i>	<i>TrAz</i>
True Number of Electrons	True simulated number of electrons at observation level	<i>(number of)</i>	<i>TrNe</i>
True Number of Muons	True simulated number of Muons at observation level	<i>(number of)</i>	<i>TrNm</i>
True Number of Photons	True simulated number of Photons at observation level	<i>(number of)</i>	<i>TrNg</i>
True Number of Hadrons	True simulated number of Hadrons at observation level	<i>(number of)</i>	<i>TrNh</i>

The plots shown in this chapter are only examples, mostly based on a subsample of the simulated data sets and only for one simulation model (QGSjet-II-04). So, applying user cuts in your own analysis can change these spectra drastically.

The quality of the reconstruction algorithm for the simulated quantities is discussed in more detail in previous chapters.

6.1 TRUE PRIMARY ENERGY (TREP)

The energy of the particle inducing the air shower is an input for the CORSIKA air shower simulation code. In our case, we simulated showers with a primary energy following a power law spectrum with a slope of '-2':

$$dN/dE_0 \propto E_0^{-2}$$

As the real spectral index is about '-2.7', the spectral index of '-2' is a compromise. Simulating with the correct spectral index requires many events simulated at low energies to get enough statistics at highest energies that is in our case 10^{18} eV, with the advantage that nearly no corrections would be necessary. On the other hand the spectral index of '-2' reduces the simulation time and the disk spaces required at the expense of complex corrections being applied during data analysis.

Fig. 6.1.1a-c show the input energy spectrum for a standard simulation set of the showers reconstructed by KRETA for the three detector components KASCADE, GRANDE and CALORIMETER together with the respective input spectrum from CORSIKA without any cuts (black). The differences are caused by the quality cuts applied, no additional analysis cuts are applied for the central hadron calorimeter. The deviation from linearity starts for KASCADE data below 10^{15} eV (red curve) which denotes that the reconstruction algorithm is not fully efficient below 1 PeV, for GRANDE (green curve) full efficiency is reached around 10^{16} eV, while the CALORIMETER (blue curve) is linear nearly over the whole range.

True Shower Simulation Data in KCDC

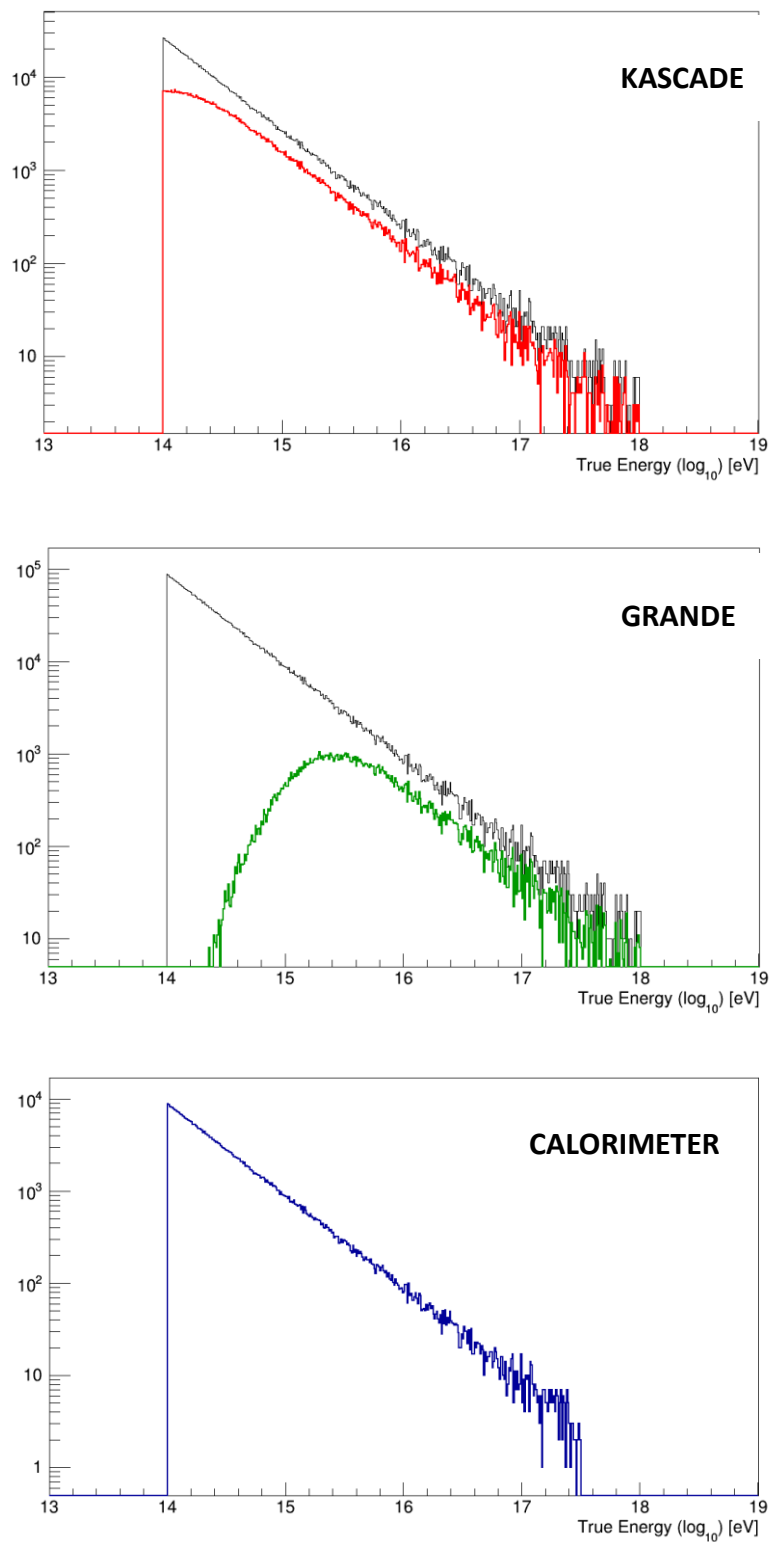


Fig. 6.1.1a-c *Spectrum of the true energy of incident particles in $[\log_{10}]$ eV simulated for : red: KASCADE; green: GRANDE; blue: CALORIMETER black: simulations without cuts*

6.2 TRUE PRIMARY PARTICLE ID (TRPP)

The ID of the particle inducing the air shower is an input for the CORSIKA air shower simulation code. We simulated 5 primaries representing 5 different mass groups and photons. These primaries and their respective IDs are:

proton	ID= 14	representing the lightest mass
helium	ID= 402	representing a light mass group
carbon	ID= 1206	representing the CNO-group
silicon	ID= 2814	representing a medium heavy mass group
iron	ID= 5626	representing the heaviest mass
gamma	ID= 1	representing the photons

6.3 TRUE SHOWER DIRECTION (TRZE, TRAZ)

The zenith angle and the azimuth angle of the incident particles are input parameters for the CORSIKA air shower simulation code. The zenith angle spectrum reaches from 0° to 42° in simulation with the shape shown in fig. 6.3.1. The zenith angle is selected at random in this interval to match equal particle fluxes from all solid angle elements of the sky and a registration by a horizontal flat detector arrangement.

As we use the same reconstruction algorithm for simulations and for measured data where the fit parameters are only fine-tuned up to about 40° , there is no use in simulating larger zenith angles because the angular resolution drops significantly above about $\theta > 40^\circ$.

Fig. 6.3.1 shows the zenith angle spectrum for a standard simulation set of the showers reconstructed by KRETA as an example for the detector component KASCADE (red) together with the input spectrum from CORSIKA (black). The differences are caused by the standard quality cuts applied.

The azimuth angle is always simulated between 0° and 360° where for $\Phi = 0^\circ$ the shower axis points to the North, $\Phi = 90^\circ$ it points to the East.

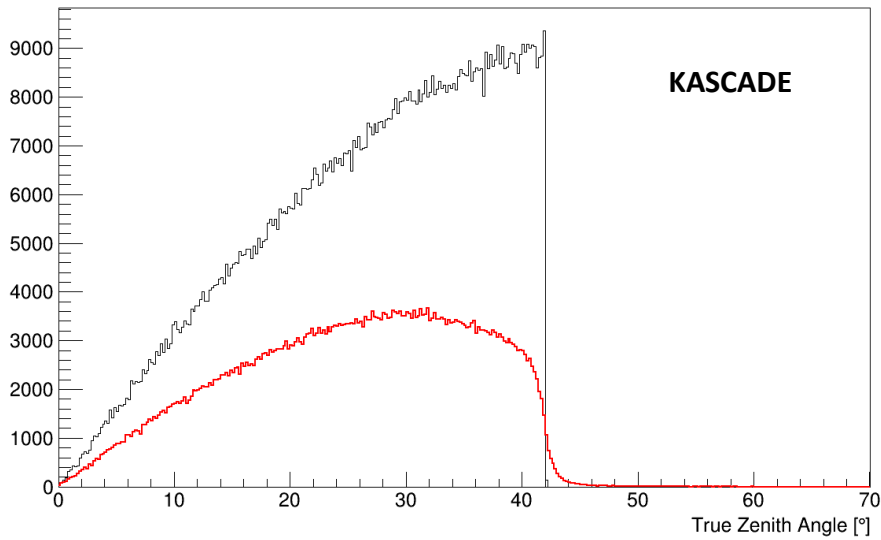


Fig. 6.3.1 *Spectrum of the true zenith angle of the incident particles in [°] simulated for : red: KASCADE; black: simulations without standard quality cuts*

Fig. 6.3.2 shows the azimuth angle spectrum for a standard simulation set of the showers reconstructed by KRETA as an example for the detector component KASCADE (red) and the input spectrum from CORSIKA (black). The differences are caused by the KASCADE standard cuts applied especially the 91m radius cut as described in chapter 3.

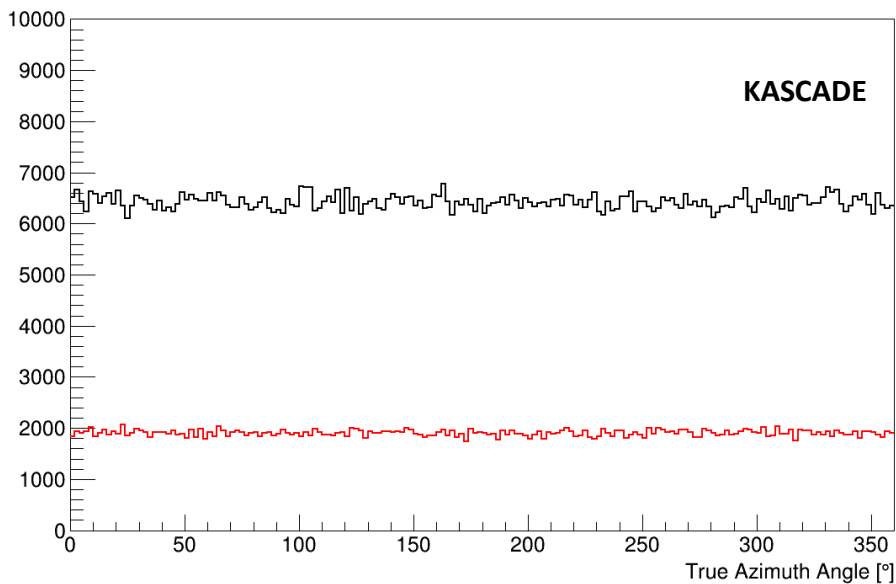


Fig. 6.3.2 *Spectrum of the true azimuth angle of the incident particles in [°] simulated for : red: KASCADE; black: simulations without standard quality cuts*

6.4 TRUE NUMBERS OF ELECTRONS (TRNE)

The **true number of electrons** is derived from the CORSIKA output as the number of electrons tracked down to the observation level of KASCADE at 110 m asl. Only electrons above 3 MeV low energy cut-off are taken into account.

Fig 6.4.1 shows the N_e spectra for the 5 different mass groups simulated in KASCADE, proton (blue), helium (purple), carbon (black), silicon (green) and iron (red).

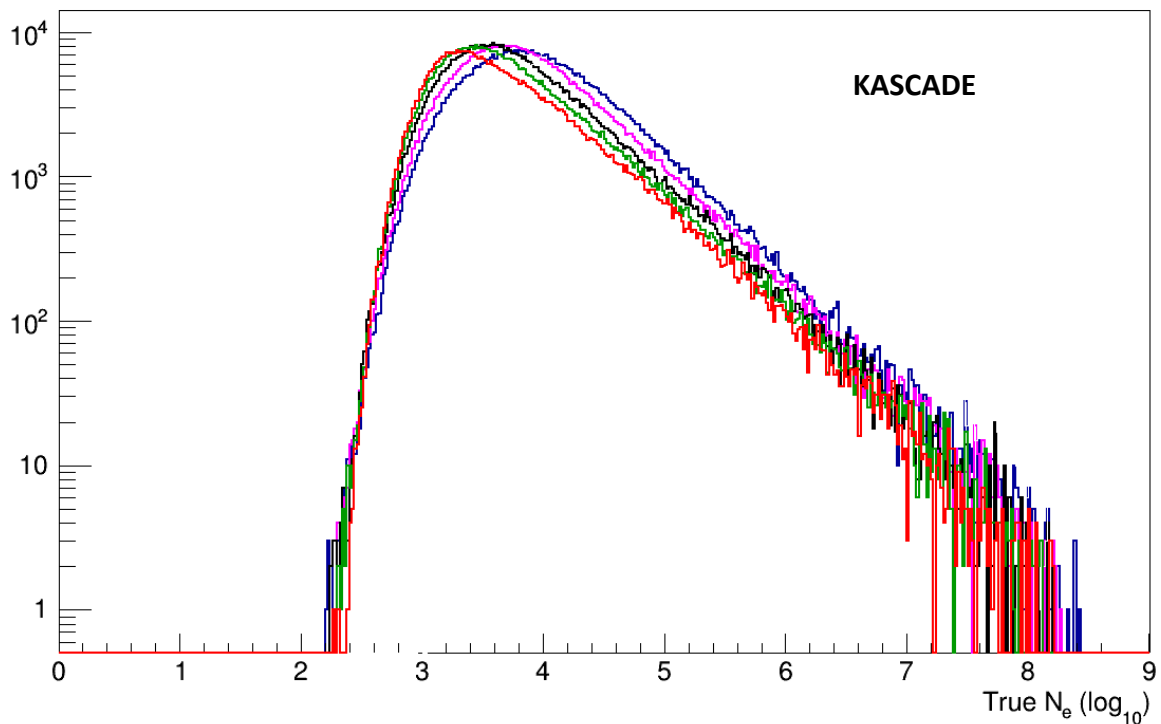


Fig. 6.4.1 *Spectrum of the number of electrons at observation level of KASCADE; simulated are: proton (blue), helium (purple), carbon (black), silicon (green) and iron (red).*

6.5 TRUE NUMBERS OF MUONS (TRNM)

The **true number of muons** is derived from the CORSIKA output as the number of muons tracked down to the observation level of KASCADE at 110 m asl. Only muons above 100 MeV low energy cut-off are taken into account.

Fig 6.5.1 shows the N_μ spectra for the 5 different mass groups used in KASCADE, proton (blue), helium (purple), carbon (black), silicon (green) and iron (red).

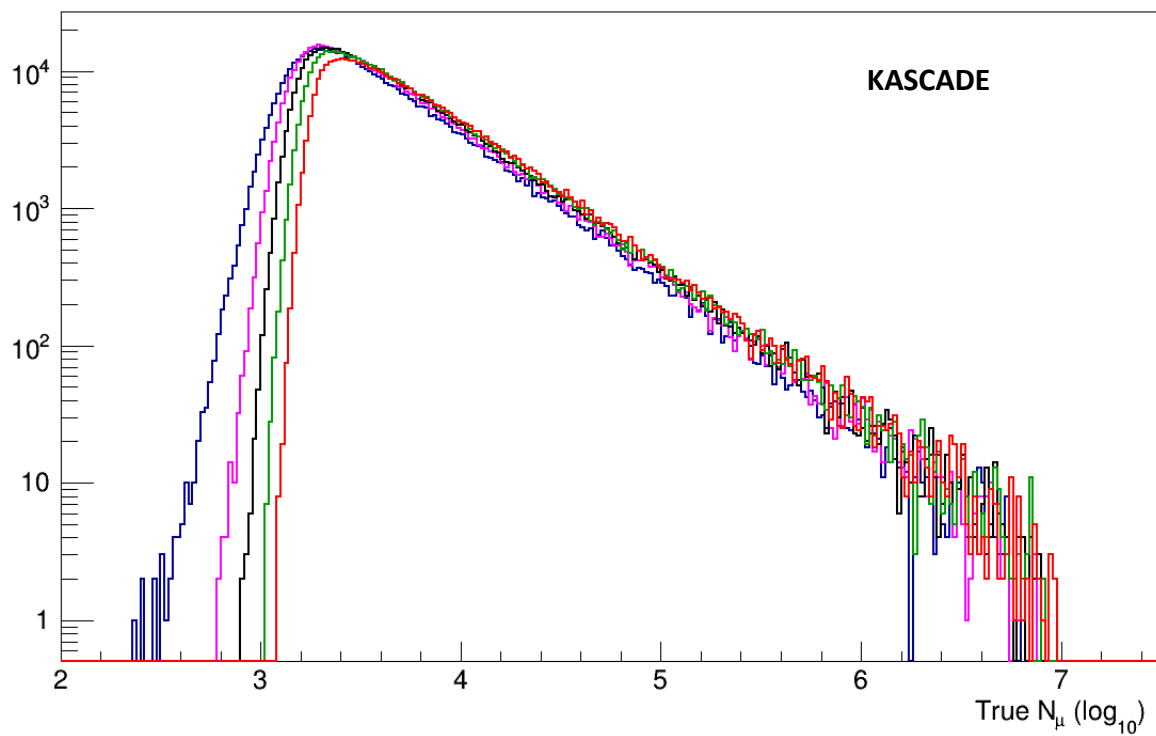


Fig. 6.5.1 *Spectrum of the number of muons at observation level of KASCADE; simulated are: proton (blue), helium (purple), carbon (black), silicon (green) and iron (red).*

6.6 TRUE NUMBERS OF PHOTONS (TRNP)

The **true number of photons** is derived from the CORSIKA output as the number of photons and π^0 tracked down to the observation level of KASCADE at 110 m asl. Only photons and π^0 above 3 MeV low energy cut-off are taken into account.

Fig 6.6.1 shows the $\gamma + \pi^0$ spectra for the 5 different mass groups used in KASCADE, proton (blue), helium (purple), carbon (black), silicon (green) and iron (red).

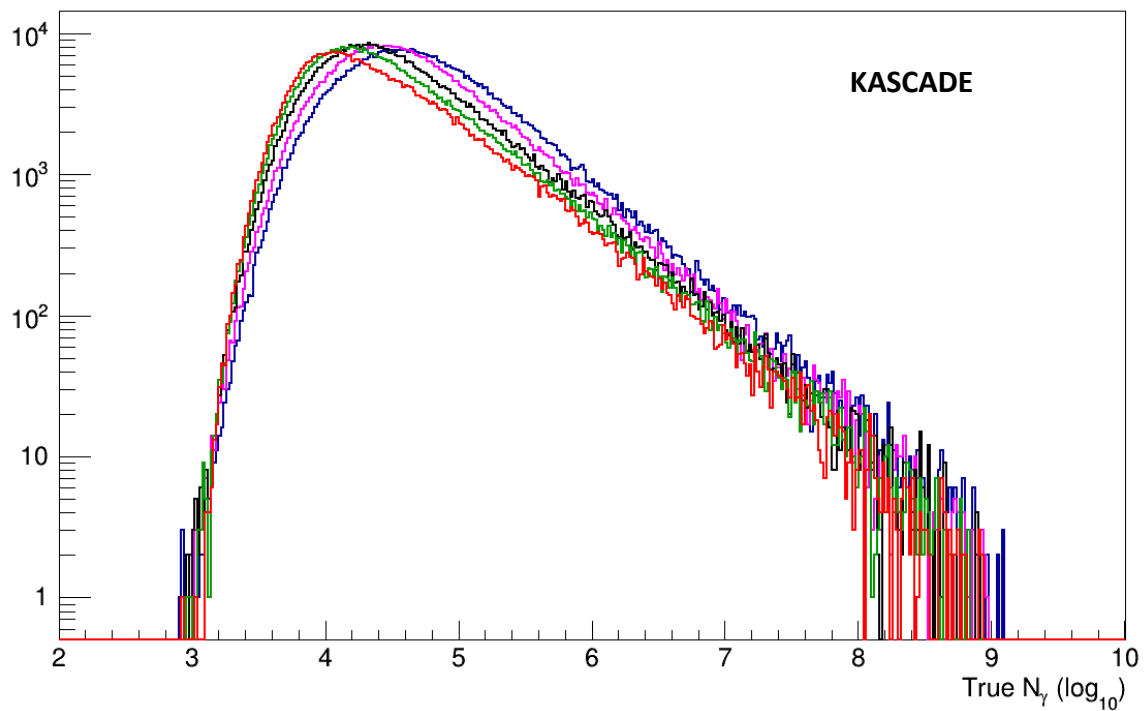


Fig. 6.6.1 *Spectrum of the number of γ and π^0 at observation level of KASCADE; simulated are: proton (blue), helium (purple), carbon (black), silicon (green) and iron (red).*

6.7 TRUE NUMBERS OF HADRONS (TRNH)

The **true number of hadrons** is derived from the CORSIKA output as the number of hadrons tracked down to the observation level of KASCADE at 110 m asl. Only hadrons above 100 MeV low energy cut-off are taken into account.

Fig 6.7.1 shows the hadron spectra for the 5 different mass groups used in KASCADE, proton (blue), helium (purple), carbon (black), silicon (green) and iron (red).

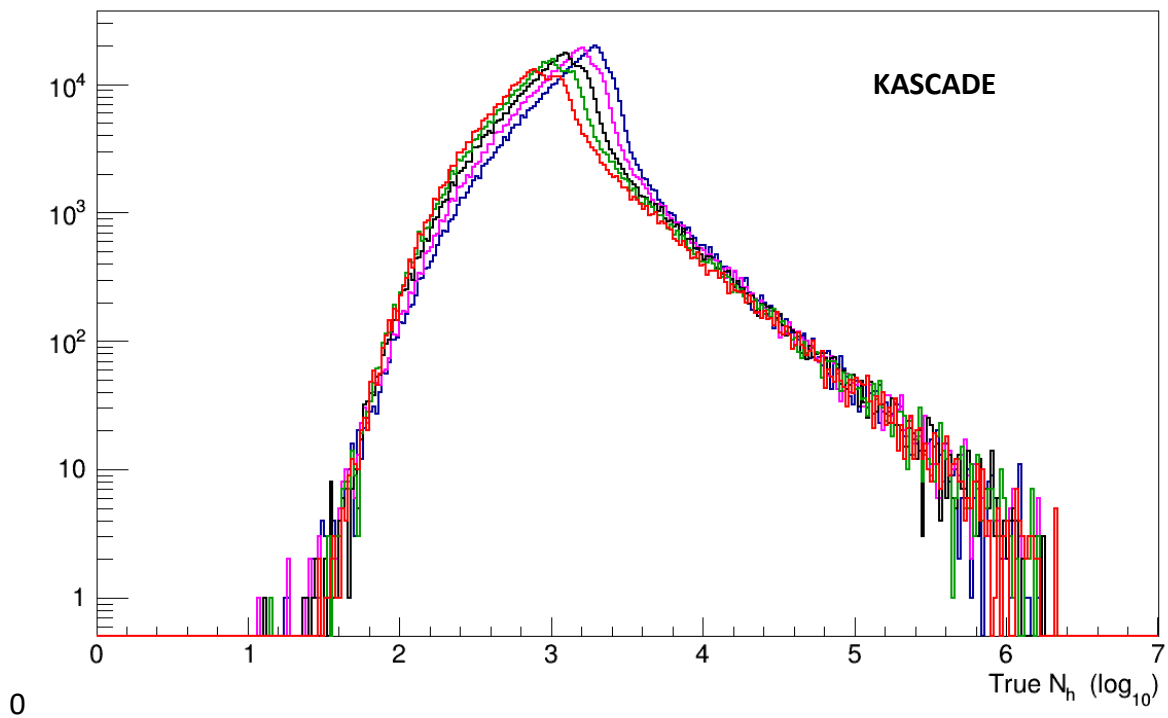


Fig. 6.7.1 *Spectrum of the number of hadrons at observation level of KASCADE; simulated are: proton (blue), helium (purple), carbon (black), silicon (green) and iron (red).*

6.8 TRUE SHOWER CORE POSITION (TRXC, TRYC)

The **true shower core position** is derived from the detector simulation (CRES) output defined as the position within the detector area where the shower centre is located. In the detector simulations this centre can be chosen when initialising the detector simulation code. The core positions are uniformly distributed over the whole detector area, even beyond the border, without any fiducial area cuts applied.

Figs. 6.8.1a-c show the shower core distributions within the areas of the 3 detector components.

KASCADE: Extensive air showers with a core position outside the detector area have a great probability for being incorrectly reconstructed. Therefore, only showers with a maximum core distance less than 91 m radius from the centre of the detector area are taken into account which reduces the fiducial area by about 35%. The regular structure is caused by an artefact in the reconstruction algorithm, which causes for simulations the centre of the shower core

True Shower Simulation Data in KCDC

to be drawn towards the stations with the highest measured energy deposits. In the centre of the array the Central Calorimeter is located, thus four stations are missing. The two detector stations north of the Central Calorimeter are a little dislocated because of the main building.

GRANDE: The strange shape of the core distribution of reconstructed showers is caused by the cuts applied mainly that the highest energy deposit is not in a border station. Again, the reconstruction algorithm causes the centre of the shower core to be drawn towards the stations with the highest measured energy deposits.

CALORIMETER: The dotted line in fig 6.8.1c marks the active detection area of the central calorimeter

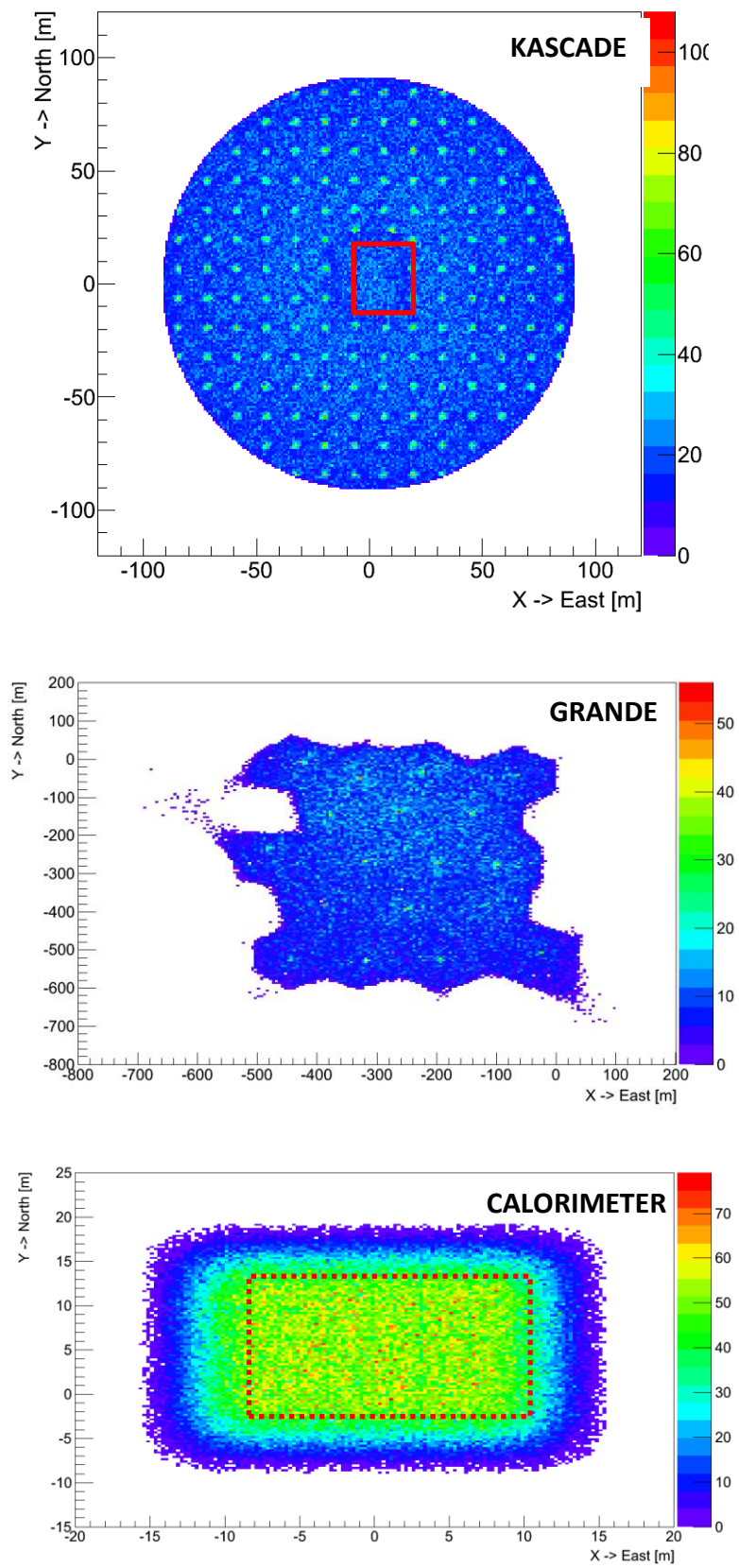


Fig. 6.8.1a-c Shower core distributions for simulated particles reconstructed with KRETA for KASCADE (a), GRANDE (b) and CALORIMETER (c)

7 SIMULATION DATA ANALYSIS HELPS

This chapter provides some valuable information on how to deal with the simulated KASCADE and GRANDE data, based on the experience of more than 20 years of data analysis.

7.1 CUTS

Concerning applied cuts we distinguish between ‘**Data Selection Cuts**’ and ‘**Advised Cuts**’. The first are already applied on the data published, the latter are highly recommended (see also chapter 7.1.4.). These quality cuts are regarded by the collaboration to be absolutely necessary to guarantee a constant quality of the data sets published.

7.1.1 QUALITY CUTS FOR SIMULATED KASCADE SHOWERS

The ‘**Data Selection Cuts KASCADE**’ have been applied while generating the simulation root files and sometimes differ from the quality cuts of the measured data.

These Cuts are:

- **the shower reconstruction in the KASCADE Array Processor was successful;**
all reconstruction steps have been performed without failure.
- **the distance to the shower core is < 91m;**
the reconstructed shower core is within a 91m radius around the centre of the KASCADE array. This cut is applied to get rid of so called ‘border effects’ which occur when a shower is reconstructed close to the border and one cannot distinguish if the shower core is inside or outside the array. In this case the lateral density fit function is meaningless.
- **0.1 < AGE < 1.48;**
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 0.1 to 1.48. Common shower values however range from 0.6 to 1.3.
- **zenith angle ZE < 60°;**
the KASCADE experiment was designed to record events with a zenith angle well below 60°. Above that value the reconstruction is rather likely to produce nonsense. As we analyse showers only up to 40°, the upper zenith angle limit for the simulations is 42°.
- **N_e > 100;**
this cut is just applied remove the non-physical rubbish

- **$N_{\mu} > 100$;**
this cut is just applied remove the non-physical rubbish

The data published do not contain events which did not survive ALL 'Data Selection Cuts KASCADE' listed above.

7.1.2 QUALITY CUTS FOR SIMULATED GRANDE SHOWERS

The '**Data Selection Cuts GRANDE**' have been applied while generating the simulation root files and sometimes differ from the quality cuts of the measured data.

These Cuts are:

- **7/7 coincidence is present ;**
all 7 stations from at least on GRANDE hexagon have triggered
- **highest energy deposit is not in a border station;**
station with max energy deposit is not at the GRANDE array border. This cut is applied to get rid of so called 'border effects' which occur when a shower is reconstructed close to the border and one cannot distinguish if the shower core is inside or outside the array. In this case the lateral density fit function is meaningless.
- **the GRANDE array reconstruction was successful;**
- **$-0.385 < AGE < 1.485$;**
GRANDE 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 -0.385 to +1.485. Common shower values however should not be negative.
- **$N_{ch} > 11111$;**
this cut is applied remove the non-physical rubbish.
- **$N_{\mu} > 1500$;**
this cut is applied remove the nonphysical rubbish.

The data published do not contain events which did not survive ALL 'Data Selection Cuts GRANDE' listed above.

7.1.3 QUALITY CUTS FOR SIMULATED CALORIMETER SHOWERS

For the simulations no '**Data Selection Cuts CALORIMETER**' have been applied while generating the root files.

7.1.4 ADVISED CUTS

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

for KASCADE simulations:

- **0.0 < AGE < 1.3;**
even though the reconstructed value for the age parameter is between 0.1 and 1.48 a common shower reaches from 0.0 to 1.3.
- **$N_e > 100000$;**
this cut is just applied to remove the non-physical rubbish

for GRANDE:

- **fiducial area**
for our GRANDE data analysis we mostly used the following cuts on the shower core position for the fiducial area:
X-cut: $-420\text{m} < X_c < -50\text{m}$
Y-cut: $-550\text{m} < Y_c < -30\text{m}$

7.2 EXPERT'S ADVICES

Here are some advices that 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 parameters are deduced with help of a Monte-Carlo Simulation sets optimized for the zenith angle range 0° to 18° (see chapter 3.1). 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 deposit value '0' 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 7.3 and appendix-A. (section 7.4 and appendix-B for GRANDE respectively).
Basically the same applies for the quantity 'Arrival Times'. But here only stations marked as active 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 'array', 'grande' and 'calorimeter'. 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 data:
https://kcdc.iap.kit.edu/static/txt/KCDC_analyze_example.C.gz ,
for simulation:
https://kcdc.iap.kit.edu/static/txt/KCDC_analyze_simulations_example.C.gz .

7.3 CALCULATION OF KASCADE DETECTOR STATION LOCATIONS FROM ID

For the 'e/ γ -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 for μ -detectors for KASCADE. The allocation table and the python-code fragment to calculate the real position of the KASCADE stations in KASCADE coordinates are given in [appendix 'A'](#).

7.4 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 to calculate the real position of the respective GRANDE station in KASCADE coordinates is given in [appendix 'B'](#).

8 SIMULATION DATA SETS

With KCDC we offer 229 root files with simulated data for direct download separately for the three detector components KASCADE, GRANDE and CALORIMETER. The simulation data sets cover the same energy ranges except for the calorimeter where, due to punch through, no particles with primary energies above $3.16 \cdot 10^{17}$ eV have been simulated.

All seven High Energy Interaction Models have been simulated under the same conditions, which are:

Parameter	Range
Energy range (Standard Set)	$10^{14} < E_0 < 10^{18}$ eV
Energy range (High Energy Extension)	$5.62 \cdot 10^{17} < E_0 < 3.16 \cdot 10^{18}$ eV
Spectral index (slope)	-2.00
Zenith angle (pr,he,co,si,fe)	0.0° - 42.0°
Zenith angle (γ)	0.0° - 60.0°
Azimuth angle	0.0° - 360.0°
Observation level	110 m asl
Transition energy	200 GeV (E_{lab}) ¹⁾
Energy cutoff hadrons	100 MeV
Energy cutoff electrons	3 MeV
Energy cutoff muons	100 MeV
Energy cutoff photons/pions	3 MeV
Magnetic Field (horizontal component)	20.0 μ T
Magnetic Field (vertical component)	43.2 μ T

¹⁾ transition energy (E_{lab} in GeV) between high and low-energy hadronic interaction models

In the following sections the available simulation sets are listed.

- col 1 primary particle initiating the shower
- col 2 number of showers simulated with the parameters listed in in table above times the factor of reuses
- col 3 number of showers surviving all quality cuts for the respective detector component i.e. the number of showers in the download root files
- col 4 root file size (the file size of the zipped download file is a factor of two smaller)
- col 5 root download file name

8.1 KASCADE SIMULATION DATA SETS

8.1.1 QGSJET-II-02 & FLUKA 2002.4

QGSjet-II-02 & FLUKA 2002.4 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	256,948 * 3	342,696	439	KASCADE_Sim_KA_qgs-2_pr.root
helium	256,948 * 3	349,673	430	KASCADE_Sim_KA_qgs-2_he.root
carbon	256,948 * 3	340,376	402	KASCADE_Sim_KA_qgs-2_co.root
silicon	256,948 * 3	321,838	372	KASCADE_Sim_KA_qgs-2_si.root
iron	256,948 * 3	291,516	332	KASCADE_Sim_KA_qgs-2_fe.root
all 5 prim's	1,284,740 * 3	1,646,099	1977	KASCADE_Sim_KA_qgs-2_5prim.root
gamma	205,596 * 3	13,858	20	KASCADE_Sim_KA_qgs-2_gm.root

QGSjet-II-02 & FLUKA 2002.4 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	27 * 3	48	136	KASCADE_Sim_KA_qgs-2_HE_pr.root
helium	28 * 3	52	147	KASCADE_Sim_KA_qgs-2_HE_he.root
carbon	25 * 3	42	121	KASCADE_Sim_KA_qgs-2_HE_co.root
silicon	30 * 3	47	129	KASCADE_Sim_KA_qgs-2_HE_si.root
iron	30 * 3	47	134	KASCADE_Sim_KA_qgs-2_HE_fe.root
all 5 prim's	140 * 3	236	604	KASCADE_Sim_KA_qgs-2_HE_5prim.root
gamma	23 * 3	33	108	KASCADE_Sim_KA_qgs-2_HE_gm.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.1.2 QGSJET-II-04 & FLUKA 2012.2.14_32

QGSjet-II-04 & FLUKA 2012.2.14_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	963,555 * 3	1,293,953	1,625	KASCADE_Sim_KA_qgs-4_pr1.root
helium	963,555 * 3	1,301,338	1,566	KASCADE_Sim_KA_qgs-4_he1.root
carbon	963,555 * 3	1,251,160	1,455	KASCADE_Sim_KA_qgs-4_co1.root
silicon	963,555 * 3	1,174,480	1,336	KASCADE_Sim_KA_qgs-4_si1.root
iron	963,555 * 3	1,056,257	1,188	KASCADE_Sim_KA_qgs-4_fe1.root
all 5 prim's	2,248,295 * 3	6,077,168	7,170	KASCADE_Sim_KA_qgs-4_5prim1.root
gamma	822,384 * 3	59,237	82	KASCADE_Sim_KA_qgs-4_gm1.root

QGSjet-II-04 & FLUKA 2012.2.14_32 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	90 * 3	138	351	KASCADE_Sim_KA_qgs-4_HE_pr1.root
helium	90 * 3	152	376	KASCADE_Sim_KA_qgs-4_HE_he1.root
carbon	90 * 3	143	357	KASCADE_Sim_KA_qgs-4_HE_co1.root
silicon	90 * 3	132	328	KASCADE_Sim_KA_qgs-4_HE_si1.root
iron	90 * 3	131	325	KASCADE_Sim_KA_qgs-4_HE_fe1.root
all 5 prim's	450 * 3	696	1,672	KASCADE_Sim_KA_qgs-4_HE_5prim1.root
gamma	69 * 3	113	339	KASCADE_Sim_KA_qgs-4_HE_gm1.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.1.3 EPOS 1.99 & FLUKA 2008.3

EPOS 1.99 & FLUKA 2008.3 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	256,948 * 3	332,638	413	KASCADE_Sim_KA_epos-199_pr.root
helium	256,948 * 3	331,082	396	KASCADE_Sim_KA_epos-199_he.root
carbon	256,948 * 3	316,927	366	KASCADE_Sim_KA_epos-199_co.root
silicon	256,948 * 3	296,444	334	KASCADE_Sim_KA_epos-199_si.root
iron	256,948 * 3	270,600	302	KASCADE_Sim_KA_epos-199_fe.root
all 5 prim's	1,284,740 * 3	1,547,691	1810	KASCADE_Sim_KA_epos-199_5prim.root

EPOS 1.99 & FLUKA 2008.3 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	29 * 3	42	117	KASCADE_Sim_KA_epos-199_HE_pr.root
helium	30 * 3	43	118	KASCADE_Sim_KA_epos-199_HE_he.root
carbon	30 * 3	35	102	KASCADE_Sim_KA_epos-199_HE_co.root
silicon	30 * 3	47	130	KASCADE_Sim_KA_epos-199_HE_si.root
iron	30 * 3	41	117	KASCADE_Sim_KA_epos-199_HE_fe.root
all 5 prim's	149 * 3	207	521	KASCADE_Sim_KA_epos-199_HE_5prim.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.1.4 EPOS LHC & FLUKA 2011.2b.4_32

EPOS LHC & FLUKA 2011.2b.4_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	449,659 * 3	597,246	754	KASCADE_Sim_KA_epos-LHC_pr.root
helium	449,659 * 3	600,164	731	KASCADE_Sim_KA_epos-LHC_he.root
carbon	449,659 * 3	573,346	673	KASCADE_Sim_KA_epos-LHC_co.root
silicon	449,659 * 3	534,471	612	KASCADE_Sim_KA_epos-LHC_si.root
iron	449,659 * 3	481,967	545	KASCADE_Sim_KA_epos-LHC_fe.root
all 5 prim's	2,298,295 * 3	2,787,194	3314	KASCADE_Sim_KA_epos-LHC_5prim.root
gamma	411,192 * 3	30,535	43	KASCADE_Sim_KA_epos-LHC_gm.root

EPOS LHC & FLUKA 2011.2b.4_32 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	60 * 3	100	251	KASCADE_Sim_KA_epos-LHC_HE_pr.root
helium	60 * 3	76	196	KASCADE_Sim_KA_epos-LHC_HE_he.root
carbon	60 * 3	84	218	KASCADE_Sim_KA_epos-LHC_HE_co.root
silicon	60 * 3	88	224	KASCADE_Sim_KA_epos-LHC_HE_si.root
iron	60 * 3	84	218	KASCADE_Sim_KA_epos-LHC_HE_fe.root
all 5 prim's	300 * 3	432	1000	KASCADE_Sim_KA_epos-LHC_HE_5prim.root
gamma	46 * 3	77	244	KASCADE_Sim_KA_epos-LHC_HE_gm.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.1.5 SIBYLL 2.1 & FLUKA 2008.3

SIBYLL 2.1 & FLUKA 2008.3 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	256,948 * 3	331,292	416	KASCADE_Sim_KA_sibyll-21_pr.root
helium	256,948 * 3	338,234	408	KASCADE_Sim_KA_sibyll-21_he.root
carbon	256,948 * 3	328,929	383	KASCADE_Sim_KA_sibyll-21_co.root
silicon	256,948 * 3	312,520	355	KASCADE_Sim_KA_sibyll-21_si.root
iron	256,948 * 3	286,327	321	KASCADE_Sim_KA_sibyll-21_fe.root
all 5 prim's	1,284,740 * 3	1,597,302	1883	KASCADE_Sim_KA_sibyll-21_5prim.root

SIBYLL 2.1 & FLUKA 2008.3 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	28 * 3	48	141	KASCADE_Sim_KA_sibyll-21_HE_pr.root
helium	29 * 3	57	152	KASCADE_Sim_KA_sibyll-21_HE_he.root
carbon	30 * 3	56	157	KASCADE_Sim_KA_sibyll-21_HE_co.root
silicon	30 * 3	43	126	KASCADE_Sim_KA_sibyll-21_HE_si.root
iron	30 * 3	52	143	KASCADE_Sim_KA_sibyll-21_HE_fe.root
all 5 prim's	147 * 3	256	655	KASCADE_Sim_KA_sibyll-21_HE_5prim.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.1.6 SIBYLL 2.3 & FLUKA 2011.2c.3_32

SIBYLL 2.3 & FLUKA 2011.2c.3_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	451,713 * 3	615,349	785	KASCADE_Sim_KA_sibyll-23_pr.root
helium	451,713 * 3	613,773	750	KASCADE_Sim_KA_sibyll-23_he.root
carbon	451,713 * 3	590,376	696	KASCADE_Sim_KA_sibyll-23_co.root
silicon	451,713 * 3	548,307	631	KASCADE_Sim_KA_sibyll-23_si.root
iron	451,713 * 3	494,663	562	KASCADE_Sim_KA_sibyll-23_fe.root
all 5 prim's	2,258,565 * 3	2,862,468	3424	KASCADE_Sim_KA_sibyll-23_5prim.root

SIBYLL 2.3 & FLUKA 2011.2c.3_32 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	60 * 3	88	223	KASCADE_Sim_KA_sibyll-23_HE_pr.root
helium	60 * 3	95	240	KASCADE_Sim_KA_sibyll-23_HE_he.root
carbon	60 * 3	92	230	KASCADE_Sim_KA_sibyll-23_HE_co.root
silicon	60 * 3	84	218	KASCADE_Sim_KA_sibyll-23_HE_si.root
iron	60 * 3	88	221	KASCADE_Sim_KA_sibyll-23_HE_fe.root
all 5 prim's	300 * 3	447	1130	KASCADE_Sim_KA_sibyll-23_HE_5prim.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.1.7 SIBYLL 2.3c & FLUKA 2011.2c.3_64

SIBYLL 2.3c & FLUKA 2011.2c.3_64 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	452,740 * 3	621,337	799	KASCADE_Sim_KA_sibyll-23c_pr.root
helium	452,740 * 3	621,624	763	KASCADE_Sim_KA_sibyll-23c_he.root
carbon	452,740 * 3	599,050	709	KASCADE_Sim_KA_sibyll-23c_co.root
silicon	452,740 * 3	557,439	642	KASCADE_Sim_KA_sibyll-23c_si.root
iron	452,740 * 3	502,531	571	KASCADE_Sim_KA_sibyll-23c_fe.root
all 5 prim's	2,263,700 * 3	2,901,981	3484	KASCADE_Sim_KA_sibyll-23c_5prim.root
gamma	411,188 * 3	30,743	44	KASCADE_Sim_KA_sibyll-23c_gm.root

SIBYLL 2.3c & FLUKA 2011.2c.3_64 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	60 * 3	104	258	KASCADE_Sim_KA_sibyll-23c_HE_pr.root
helium	60 * 3	92	238	KASCADE_Sim_KA_sibyll-23c_HE_he.root
carbon	60 * 3	89	218	KASCADE_Sim_KA_sibyll-23c_HE_co.root
silicon	60 * 3	98	253	KASCADE_Sim_KA_sibyll-23c_HE_si.root
iron	60 * 3	84	212	KASCADE_Sim_KA_sibyll-23c_HE_fe.root
all 5 prim's	300 * 3	467	1100	KASCADE_Sim_KA_sibyll-23c_HE_5prim.root
gamma	46 * 3	80	243	KASCADE_Sim_KA_sibyll-23c_HE_gm.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.1.8 SIBYLL 2.3D & FLUKA 2011.2x4-64

SIBYLL 2.3d & FLUKA 2011.2x4-64 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	456,848 * 3	623,995	794	KASCADE_Sim_KA_sibyll-23d_pr.root
helium	456,848 * 3	622,756	761	KASCADE_Sim_KA_sibyll-23d_he.root
carbon	456,848 * 3	597,837	704	KASCADE_Sim_KA_sibyll-23d_co.root
silicon	456,848 * 3	557,804	641	KASCADE_Sim_KA_sibyll-23d_si.root
iron	456,848 * 3	503,711	572	KASCADE_Sim_KA_sibyll-23d_fe.root
all 5 prim's	2,284,240 * 3	2,906,103	3473	KASCADE_Sim_KA_sibyll-23d_5prim.root
gamma	411,192 * 3	30,484	43	KASCADE_Sim_KA_sibyll-23d_gm.root

SIBYLL 2.3d & FLUKA 2011.2x4-64 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	60 * 3	86	232	KASCADE_Sim_KA_sibyll-23d_HE_pr.root
helium	60 * 3	97	242	KASCADE_Sim_KA_sibyll-23d_HE_he.root
carbon	60 * 3	83	214	KASCADE_Sim_KA_sibyll-23d_HE_co.root
silicon	60 * 3	78	204	KASCADE_Sim_KA_sibyll-23d_HE_si.root
iron	60 * 3	83	211	KASCADE_Sim_KA_sibyll-23d_HE_fe.root
all 5 prim's	300 * 3	427	1000	KASCADE_Sim_KA_sibyll-23d_HE_5prim.root
gamma	46 * 3	77	172	KASCADE_Sim_KA_sibyll-23d_HE_gm.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.2 GRANDE SIMULATION DATA SETS

8.2.1 QGSJET-II-02 & FLUKA 2002.4

QGSjet-II-02 & FLUKA 2002.4 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	256,948 * 10	69,624	67	KASCADE_Sim_GR_qgs-2_pr.root
helium	256,948 * 10	62,729	63	KASCADE_Sim_GR_qgs-2_he.root
carbon	256,948 * 10	56,182	58	KASCADE_Sim_GR_qgs-2_co.root
silicon	256,948 * 10	52,223	56	KASCADE_Sim_GR_qgs-2_si.root
iron	256,948 * 10	48,518	53	KASCADE_Sim_GR_qgs-2_fe.root
all 5 prim's	1,284,740*10	289,276	297	KASCADE_Sim_GR_qgs-2_5prim.root
gamma	205,596 * 10	13,795	9	KASCADE_Sim_GR_qgs-2_gm.root

QGSjet-II-02 & FLUKA 2002.4 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	30 * 10	126	346	KASCADE_Sim_GR_qgs-2_HE_pr.root
helium	30 * 10	148	384	KASCADE_Sim_GR_qgs-2_HE_he.root
carbon	30 * 10	143	381	KASCADE_Sim_GR_qgs-2_HE_co.root
silicon	30 * 10	119	319	KASCADE_Sim_GR_qgs-2_HE_si.root
iron	30 * 10	146	371	KASCADE_Sim_GR_qgs-2_HE_fe.root
all 5 prim's	148 * 10	682	1790	KASCADE_Sim_GR_qgs-2_HE_5prim.root
gamma	23 * 10	108	265	KASCADE_Sim_GR_qgs-2_HE_gm.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.2.2 QGSJET-II-04 & FLUKA 2012.2.14_32

QGSjet-II-04 & FLUKA 2012.2.14_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	963,555 * 10	255,970	248	KASCADE_Sim_GR_qgs-4_pr1.root
helium	963,555 * 10	230,339	232	KASCADE_Sim_GR_qgs-4_he1.root
carbon	963,555 * 10	206,955	216	KASCADE_Sim_GR_qgs-4_co1.root
silicon	963,555 * 10	190,111	204	KASCADE_Sim_GR_qgs-4_si1.root
iron	963,555 * 10	174,993	191	KASCADE_Sim_GR_qgs-4_fe1.root
all 5 prim's	2,248,295*10	1,058,368	1,092	KASCADE_Sim_GR_qgs-4_5prim1.root
gamma	822,384 * 10	57,400	38	KASCADE_Sim_GR_qgs-4_gm1.root

QGSjet-II-02 & FLUKA 2012.2.14_32 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	90 * 10	442	1,134	KASCADE_Sim_GR_qgs-4_HE_pr1.root
helium	90 * 10	427	1,191	KASCADE_Sim_GR_qgs-4_HE_he1.root
carbon	90 * 10	452	1,148	KASCADE_Sim_GR_qgs-4_HE_co1.root
silicon	90 * 10	471	1,209	KASCADE_Sim_GR_qgs-4_HE_si1.root
iron	90 * 10	449	1,191	KASCADE_Sim_GR_qgs-4_HE_fe1.root
all 5 prim's	450 * 10	2,241	5,715	KASCADE_Sim_GR_qgs-4_HE_5prim1.root
gamma	69 * 10	334	788	KASCADE_Sim_GR_qgs-4_HE_gm1.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.2.3 EPOS 1.99 & FLUKA 2008.3

EPOS 1.99 & FLUKA 2008.3 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	256,948 * 10	65,801	66	KASCADE_Sim_GR_epos-199_pr.root
helium	256,948 * 10	59,151	62	KASCADE_Sim_GR_epos-199_he.root
carbon	256,948 * 10	52,100	56	KASCADE_Sim_GR_epos-199_co.root
silicon	256,948 * 10	47,749	53	KASCADE_Sim_GR_epos-199_si.root
iron	256,948 * 10	43,637	50	KASCADE_Sim_GR_epos-199_fe.root
all 5 prim's	1,284,740 * 10	268,438	285	KASCADE_Sim_GR_epos-199_5prim.root

EPOS 1.99 & FLUKA 2008.3 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	30 * 10	133	353	KASCADE_Sim_GR_epos-199_HE_pr.root
helium	30 * 10	129	353	KASCADE_Sim_GR_epos-199_HE_he.root
carbon	30 * 10	145	376	KASCADE_Sim_GR_epos-199_HE_co.root
silicon	30 * 10	139	367	KASCADE_Sim_GR_epos-199_HE_si.root
iron	30 * 10	156	403	KASCADE_Sim_GR_epos-199_HE_fe.root
all 5 prim's	150 * 10	702	1852	KASCADE_Sim_GR_epos-199_HE_-5prim.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.2.4 EPOS LHC & FLUKA 2011.2b.4_32

EPOS LHC & FLUKA 2011.2b.4_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	449,659 * 10	124,456	122	KASCADE_Sim_GR_epos-LHC_pr.root
helium	449,659 * 10	113,392	115	KASCADE_Sim_GR_epos-LHC_he.root
carbon	449,659 * 10	99,716	100	KASCADE_Sim_GR_epos-LHC_co.root
silicon	449,659 * 10	91,760	105	KASCADE_Sim_GR_epos-LHC_si.root
iron	449,659 * 10	83,568	93	KASCADE_Sim_GR_epos-LHC_fe.root
all 5 prim's	2,248,295*10	512,892	534	KASCADE_Sim_GR_epos-LHC_5prim.root
gamma	411,192 * 10	29,220	19	KASCADE_Sim_GR_epos-LHC_gm.root

EPOS LHC & FLUKA 2011.2b.4_32 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	60 * 10	316	796	KASCADE_Sim_GR_epos-LHC_HE_pr.root
helium	60 * 10	308	802	KASCADE_Sim_GR_epos-LHC_HE_he.root
carbon	60 * 10	304	789	KASCADE_Sim_GR_epos-LHC_HE_co.root
silicon	60 * 10	293	756	KASCADE_Sim_GR_epos-LHC_HE_si.root
iron	60 * 10	293	734	KASCADE_Sim_GR_epos-LHC_HE_fe.root
all 5 prim's	300 * 10	1514	3800	KASCADE_Sim_GR_epos-LHC_HE_5prim.root
gamma	46 * 10	220	480	KASCADE_Sim_GR_epos-LHC_HE_gm.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.2.5 SIBYLL 2.1 & FLUKA 2008.3

SIBYLL 2.1 & FLUKA 2008.3 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	256,948 * 10	62,775	60	KASCADE_Sim_GR_sibyll-21_pr.root
helium	256,948 * 10	57,277	57	KASCADE_Sim_GR_sibyll-21_he.root
carbon	256,948 * 10	51,412	53	KASCADE_Sim_GR_sibyll-21_co.root
silicon	256,948 * 10	47,276	51	KASCADE_Sim_GR_sibyll-21_si.root
iron	256,948 * 10	43,456	48	KASCADE_Sim_GR_sibyll-21_fe.root
all 5 prim's	1,284,740 * 10	262,196	269	KASCADE_Sim_GR_sibyll-21_5prim.root

SIBYLL 2.1 & FLUKA 2008.3 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	30 * 10	142	375	KASCADE_Sim_GR_sibyll-21_HE_pr.root
helium	30 * 10	133	351	KASCADE_Sim_GR_sibyll-21_HE_he.root
carbon	30 * 10	133	356	KASCADE_Sim_GR_sibyll-21_HE_co.root
silicon	30 * 10	144	397	KASCADE_Sim_GR_sibyll-21_HE_si.root
iron	30 * 10	156	414	KASCADE_Sim_GR_sibyll-21_HE_fe.root
all 5 prim's	150 * 10	708	1893	KASCADE_Sim_GR_sibyll-21_HE_5prim.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.2.6 SIBYLL 2.3 & FLUKA 2011.2c.3_32

SIBYLL 2.3 & FLUKA 2011.2c.3_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	451,713 * 10	128,972	125	KASCADE_Sim_GR_sibyll-23_pr.root
helium	451,713 * 10	115,114	116	KASCADE_Sim_GR_sibyll-23_he.root
carbon	451,713 * 10	102,568	107	KASCADE_Sim_GR_sibyll-23_co.root
silicon	451,713 * 10	93,332	100	KASCADE_Sim_GR_sibyll-23_si.root
iron	451,713 * 10	85,933	94	KASCADE_Sim_GR_sibyll-23_fe.root
all 5 prim's	2,258,565*10	525,919	542	KASCADE_Sim_GR_sibyll-23_5prim.root

SIBYLL 2.3 & FLUKA 2011.2c.3_32 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	60 * 10	290	737	KASCADE_Sim_GR_sibyll-23_HE_pr.root
helium	60 * 10	267	672	KASCADE_Sim_GR_sibyll-23_HE_he.root
carbon	60 * 10	299	763	KASCADE_Sim_GR_sibyll-23_HE_co.root
silicon	60 * 10	299	766	KASCADE_Sim_GR_sibyll-23_HE_si.root
iron	60 * 10	298	738	KASCADE_Sim_GR_sibyll-23_HE_fe.root
all 5 prim's	300 * 10	1443	3609	KASCADE_Sim_GR_sibyll-23_HE_5prim.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.2.7 SIBYLL 2.3c & FLUKA 2011.2c.3_64

SIBYLL 2.3c & FLUKA 2011.2c.3_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	452,740 * 10	131,691	126	KASCADE_Sim_GR_sibyll-23c_pr.root
helium	452,740 * 10	116,508	116	KASCADE_Sim_GR_sibyll-23c_he.root
carbon	452,740 * 10	104,995	108	KASCADE_Sim_GR_sibyll-23c_co.root
silicon	452,740 * 10	94,206	101	KASCADE_Sim_GR_sibyll-23c_si.root
iron	452,740 * 10	86,655	95	KASCADE_Sim_GR_sibyll-23c_fe.root
all 5 prim's	2,263,700*10	534,055	546	KASCADE_Sim_GR_sibyll-23c_5prim.root
gamma	394,926 * 10	28,954	19	KASCADE_Sim_GR_sibyll-23c_gm.root

SIBYLL 2.3c & FLUKA 2011.2c.3_32 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	60 * 10	316	801	KASCADE_Sim_GR_sibyll-23c_HE_pr.root
helium	60 * 10	295	755	KASCADE_Sim_GR_sibyll-23c_HE_he.root
carbon	60 * 10	305	798	KASCADE_Sim_GR_sibyll-23c_HE_co.root
silicon	60 * 10	267	658	KASCADE_Sim_GR_sibyll-23c_HE_si.root
iron	70 * 10	299	794	KASCADE_Sim_GR_sibyll-23c_HE_fe.root
all 5 prim's	300 * 10	1482	3700	KASCADE_Sim_GR_sibyll-23c_HE_5prim.root
gamma	46 * 10	243	542	KASCADE_Sim_GR_sibyll-23c_HE_gm.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.2.8 SIBYLL 2.3D & FLUKA 2011.2x4-64

SIBYLL 2.3d & FLUKA 2011.2x4-64 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	456,848 * 10	138,961	125	KASCADE_Sim_GR_sibyll-23d_pr.root
helium	456,848 * 10	114,732	116	KASCADE_Sim_GR_sibyll-23d_he.root
carbon	456,848 * 10	104,159	108	KASCADE_Sim_GR_sibyll-23d_co.root
silicon	456,848 * 10	94,133	101	KASCADE_Sim_GR_sibyll-23d_si.root
iron	456,848 * 10	87,399	96	KASCADE_Sim_GR_sibyll-23d_fe.root
all 5 prim's	2,284,240*10	529,324	546	KASCADE_Sim_GR_sibyll-23d_5prim.root
gamma	411,192 * 10	29,519	20	KASCADE_Sim_GR_sibyll-23dc_gm.root

SIBYLL 2.3d & FLUKA 2011.2x4-64 (High Energy Extension)				
Primary Particle	Events		File Size [kB]	Download File Name
	simulated	reconstruct		
proton	60 * 10	300	798	KASCADE_Sim_GR_sibyll-23d_HE_pr.root
helium	60 * 10	287	772	KASCADE_Sim_GR_sibyll-23d_HE_he.root
carbon	60 * 10	301	779	KASCADE_Sim_GR_sibyll-23d_HE_co.root
silicon	60 * 10	266	675	KASCADE_Sim_GR_sibyll-23d_HE_si.root
iron	70 * 10	299	765	KASCADE_Sim_GR_sibyll-23d_HE_fe.root
all 5 prim's	300 * 10	1453	3700	KASCADE_Sim_GR_sibyll-23d_HE_5prim.root
gamma	46 * 10	241	528	KASCADE_Sim_GR_sibyll-23d_HE_gm.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.3 CALORIMETER SIMULATION DATA SETS

8.3.1 QGSJET-II-02 & FLUKA 2002.4

QGSjet-II-02 & FLUKA 2002.4 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	256,892 * 1	256,892	273	KASCADE_Sim_CA_qgs-2_pr.root
helium	256,892 * 1	256,892	268	KASCADE_Sim_CA_qgs-2_he.root
carbon	256,892 * 1	256,892	257	KASCADE_Sim_CA_qgs-2_co.root
silicon	256,892 * 1	256,892	247	KASCADE_Sim_CA_qgs-2_si.root
iron	256,892 * 1	256,892	235	KASCADE_Sim_CA_qgs-2_fe.root
all 5 prim's	1,284,460 * 1	1,284,460	1279	KASCADE_Sim_CA_qgs-2_5prim.root

8.3.2 QGSJET-II-04 & FLUKA 2012.2.14_32

QGSjet-II-04 & FLUKA 2012.2.14_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	963,345 * 1	963,043	1,017	KASCADE_Sim_CA_qgs-4_pr1.root
helium	963,345 * 1	963,157	990	KASCADE_Sim_CA_qgs-4_he1.root
carbon	963,345 * 1	961,599	942	KASCADE_Sim_CA_qgs-4_co1.root
silicon	963,345 * 1	963,072	904	KASCADE_Sim_CA_qgs-4_si1.root
iron	963,345 * 1	963,065	858	KASCADE_Sim_CA_qgs-4_fe1.root
all 5 prim's	4,816,725 * 1	4,813,936	4,709	KASCADE_Sim_CA_qgs-4_5prim1.root
gamma	822,208 * 1	616,651	60	KASCADE_Sim_CA_qgs-4_gm1.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.3.3 EPOS 1.99 & FLUKA 2008.3

EPOS 1.99 & FLUKA 2008.3 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	256,892 * 1	256,892	261	KASCADE_Sim_CA_epos-199_pr.root
helium	256,892 * 1	256,892	254	KASCADE_Sim_CA_epos-199_he.root
carbon	256,892 * 1	256,892	240	KASCADE_Sim_CA_epos-199_co.root
silicon	256,892 * 1	256,892	229	KASCADE_Sim_CA_epos-199_si.root
iron	256,892 * 1	256,892	219	KASCADE_Sim_CA_epos-199_fe.root
all 5 prim's	1,284,460 * 1	1,284,460	1203	KASCADE_Sim_CA_epos-199_5prim.root

8.3.4 EPOS LHC & FLUKA 2011.2b.4_32

EPOS LHC & FLUKA 2011.2b.4_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	385,338 * 1	385,337	407	KASCADE_Sim_CA_epos-LHC_pr.root
helium	384,938 * 1	384,937	397	KASCADE_Sim_CA_epos-LHC_he.root
carbon	385,338 * 1	385,338	376	KASCADE_Sim_CA_epos-LHC_co.root
silicon	385,338 * 1	385,337	357	KASCADE_Sim_CA_epos-LHC_si.root
iron	385,338 * 1	385,338	338	KASCADE_Sim_CA_epos-LHC_fe.root
all 5 prim's	1,926,287 * 1	1,926,287	1875	KASCADE_Sim_CA_epos-LHC_5prim.root
gamma	205,552 * 1	205,552	20	KASCADE_Sim_CA_epos-LHC_gm.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.3.5 SIBYLL 2.1 & FLUKA 2008.3

SIBYLL 2.1 & FLUKA 2008.3 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	192,669 * 1	192,669	196	KASCADE_Sim_CA_sibyll-21_pr.root
helium	192,669 * 1	192,669	192	KASCADE_Sim_CA_sibyll-21_he.root
carbon	192,669 * 1	192,669	184	KASCADE_Sim_CA_sibyll-21_co.root
silicon	192,669 * 1	192,669	176	KASCADE_Sim_CA_sibyll-21_si.root
iron	192,669 * 1	192,669	168	KASCADE_Sim_CA_sibyll-21_fe.root
all 5 prim's	963,345 * 1	963,345	916	KASCADE_Sim_CA_sibyll-21_5prim.root

8.3.6 SIBYLL 2.3 & FLUKA 2011.2c.3_32

SIBYLL 2.3 & FLUKA 2011.2c.3_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	451,713 * 1	451,607	490	KASCADE_Sim_CA_sibyll-23_pr.root
helium	451,713 * 1	451,439	473	KASCADE_Sim_CA_sibyll-23_he.root
carbon	451,713 * 1	451,363	448	KASCADE_Sim_CA_sibyll-23_co.root
silicon	451,713 * 1	451,614	423	KASCADE_Sim_CA_sibyll-23_si.root
iron	451,713 * 1	451,575	399	KASCADE_Sim_CA_sibyll-23_fe.root
all 5 prim's	2,258,565 * 1	2,257,498	2232	KASCADE_Sim_CA_sibyll-23_5prim.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.3.7 SIBYLL 2.3c & FLUKA 2011.2c.3_64

SIBYLL 2.3c & FLUKA 2011.2c.3_32 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	452,642 * 1	451,051	495	KASCADE_Sim_CA_sibyll-23c_pr.root
helium	452,642 * 1	452,272	478	KASCADE_Sim_CA_sibyll-23c_he.root
carbon	452,642 * 1	452,544	463	KASCADE_Sim_CA_sibyll-23c_co.root
silicon	452,642 * 1	452,576	426	KASCADE_Sim_CA_sibyll-23c_si.root
iron	452,642 * 1	452,615	402	KASCADE_Sim_CA_sibyll-23c_fe.root
all 5 prim's	2,263,210*1	2,261,058	2254	KASCADE_Sim_CA_sibyll-23c_5prim.root
gamma	256,940 * 1	256,939	26	KASCADE_Sim_CA_sibyll-23c_gm.root

8.3.8 SIBYLL 2.3d & FLUKA 2011.2x4-64

SIBYLL 2.3d & FLUKA 2011.2x4-64 (standard set)				
Primary Particle	Events		File Size [MB]	Download File Name
	simulated	reconstruct		
proton	456,750 * 1	456,526	495	KASCADE_Sim_CA_sibyll-23d_pr.root
helium	456,750 * 1	456,523	478	KASCADE_Sim_CA_sibyll-23d_he.root
carbon	456,750 * 1	455,948	453	KASCADE_Sim_CA_sibyll-23d_co.root
silicon	456,750 * 1	456,633	429	KASCADE_Sim_CA_sibyll-23d_si.root
iron	456,750 * 1	456,357	406	KASCADE_Sim_CA_sibyll-23d_fe.root
all 5 prim's	2,283,750 * 1	2,281,987	2261	KASCADE_Sim_CA_sibyll-23d_5prim.root
Gamma	411,104 * 1	401,903	41	KASCADE_Sim_CA_sibyll-23d_gm.root

Note the download file size is a factor of about 2 smaller than the values given in column four because we offer only zipped files for download.

8.4 GET ROOT SIMULATIONS

From the 'KCDC' – 'Simulations' page registered users can download data sets directly just by clicking the respective download button (see fig 8.4.1). Users which are not yet registered have access to the 'General Info' page where some information around the subject of simulations for KASCADE and how to register are provided.

The 'General Info' page contains general information on how the provided data records were created and which quantities are published. Simulations for the two DataShops KASCADE and COMBINED are currently available invoked via the provided menu items.

Selecting a High Energy Simulation Model leads to the download page, which contains additional information on the individual download files (see fig 8.4.2).

[[Juergen]] | KIT | IAP | HOME | Data Privacy | Impressum | admin | logout

KIT
Karlsruhe Institute of Technology

KASCADE

KCDC

KASCADE Cosmic Ray Data Centre (KCDC) / Open β

Event Simulations for KASCADE / KASCADE-Grande

This page contains information specific to the simulations of **KASCADE-Grande** and the links for downloading the simulation ROOT files. All general information about the generation of the simulated Cosmic Ray events and their reconstruction can be found on the page [General Info](#).

- General information concerning KASCADE-Grande simulations published
- Table of simulations
- [KCDC Simulations Manual](#)

Some general information concerning the KASCADE-Grande simulations published

In the KASCADE-Grande simulations, we are publishing five elements representing different mass groups of primary cosmic ray particles, and photons, using eight different high energy hadronic interaction models from three model families.

- QGSjet-II-02 & QGSjet-II-04
- EPOS 1.99 & EPOS-LHC
- SIBYLL 2.1 & SIBYLL 2.3 & SIBYLL 2.3c & SIBYLL 2.3d

and one low energy model

- FLUKA.

invoked when the energy of the tracked particle E_{lab} is below 200 GeV.

The simulations are available for the three presently published detector components KASCADE, GRANDE and CALORIMETER (no simulations for Radio LOPES are published). These are treated differently in simulations in the sense that one CORSIKA shower is used several times for the KASCADE and the GRANDE detectors respectively. The number of reuses (3 times for KASCADE, 10 times for GRANDE and once for the CALORIMETER) is optimized to save disk space and computing time on the one hand and on the other hand to avoid too many reuses, which could cause a bias in the simulated data, especially for energy bins with only a few showers like at high energies.

The simulation data are published in a format as close as possible to the measured data published with the KCDC release NAB00. Thus, we provide six ROOT trees in every ftp download file, one more compared to the measured data:

ROOT tree	description
general	run- & event number; data arrays of energy deposits and arrival times for KASCADE and GRANDE
array	all reconstructed KASCADE quantities (E, Xc, Yc, Zc, Az, Ne, Nmu, Age)
grande	all reconstructed GRANDE quantities (Xc, Yc, Ze, Az, Nch, Nmu, Age)
calorimeter	all reconstructed CALORIMETER quantities (Nhad, Ehad)
trmc	all MC information from CORSIKA and CRES (TrEP,TRPP,TrXc,TrYc,TrZe,TrAz,TrNe,TrNg,TrNm,TrNh)
row_map	information to synchronise the trees

Table of simulations available for KASCADE-Grande

QGSjet	EPOS	SIBYLL
QGSjet-II-02	EPOS 1.99	SIBYLL 2.1
QGSjet-II-04	EPOS LHC	SIBYLL 2.3
		SIBYLL 2.3c
		SIBYLL 2.3d

Click on the model to get to download pages

KCDC OPEN - BETA - VERSION SKARAGAN 2.0 based on: KAOS (2.0.0)

Fig. 8.4.1.

KASCADE 'Simulations' for direct download

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Karlsruhe Institute of Technology

KASCADE Cosmic Ray Data Centre (KCDC) / Open β

KCDC

Air Shower Simulations with QGSjet-II-04 and FLUKA

Technical data for QGSjet-II-04 simulations

High energy model QGSjet-II-04 ($E_{lab} > 200\text{GeV}$)
 Low energy model FLUKA 2012.2.14_32 ($E_{lab} < 200\text{GeV}$)
 Energy range KASCADE $1.0 \times 10^{14} < E_0 < 1.0 \times 10^{18}$ eV (HE: $< 3.16 \times 10^{18}$ eV)
 Energy range GRANDE $1.0 \times 10^{14} < E_0 < 1.0 \times 10^{18}$ eV (HE: $< 3.16 \times 10^{18}$ eV)
 Energy range CALORIMETER $1.0 \times 10^{14} < E_0 < 3.16 \times 10^{17}$ eV

Detector component	Primary particle	Events simul * reused	Events processed	download size	download root files
KASCADE	proton	449.659 * 3	603.562	759 MB	download
	helium	449.659 * 3	607.463	732 MB	download
	carbon	449.659 * 3	583.973	680 MB	download
	silicon	449.659 * 3	547.547	624 MB	download
	iron	449.659 * 3	493.194	555 MB	download
	gamma	411.192 * 3	29.970	42,5 MB	download
GRANDE	proton	449.659 * 10	119.322	116 MB	download
	helium	449.659 * 10	107.293	109 MB	download
	carbon	449.659 * 10	96.646	102 MB	download
	silicon	449.659 * 10	88.800	96 MB	download
	iron	449.659 * 10	81.843	90 MB	download
	gamma	411.192 * 10	29.015	19,2 MB	download
CALORIMETER	proton	449.561 * 1	449.546	476 MB	download
	helium	449.561 * 1	449.561	463 MB	download
	carbon	449.561 * 1	449.550	441 MB	download
	silicon	449.561 * 1	449.556	423 MB	download
	iron	449.561 * 1	449.531	401 MB	download
	gamma	205.552 * 1	205.552	20 MB	download

QGSjet-II-04 Information

Events simul * reused denotes the number of events simulated and how often they have been reused for the respective detector component, while **Events processed** specifies the number of events surviving all quality cuts which are included in the respective root file. Clicking on the respective primary **download** link will open a dialog box to start the ftp download. **download ALL** will download the simulations of all 5 primaries in one zipped file. Gamma induced shower data are not included. For a more detailed description of the simulation sets, applied cuts and download procedure check the [KCDC Simulations Manual](#)

Fig. 8.4.2.

example download page for the QGSjet-II-04 simulation model

9 SIMULATION DATA FORMAT

Concerning the simulation data sets we offer at present only ROOT files for download via the KCDC web pages. ROOT is an object-oriented framework developed by CERN aimed at solving the data analysis challenges of high-energy physics.

9.1 ROOT FILES

Like the KASCADE/KASCADE-Grande measured data provided for download via the KCDC Data Shop, the simulation ROOT files are organised in trees. The files contain six trees, one for each detector component, one tree for the ‘general’ information where all data arrays are included, one tree for the true Monte Carlo information and a tree to map the entries for the selected detector components for each event called ‘row_map’, required to match the various detector components belonging to the same event (see table below and fig. 9.1.1.).

ROOT tree	description
general	all data arrays; run- & event-number
array	all reconstructed KASCADE quantities (E, Xc,Yc,Ze,Az,Ne,Nmu,Age)
grande	all reconstructed GRANDE quantities (Xc,Yc,Ze,Az,Nch,Nmu,Age)
calorimeter	all reconstructed CALORIMETER quantities (Nhad,Ehad)
trmc	all MC information from CORSIKA and CRES (TrEP,TRPP,TrXc,TrYc, TrZe, TrAz,TrNe,TrNg,TrNm,TrNh)
row_map	information to synchronise the trees

Simulation Data Format

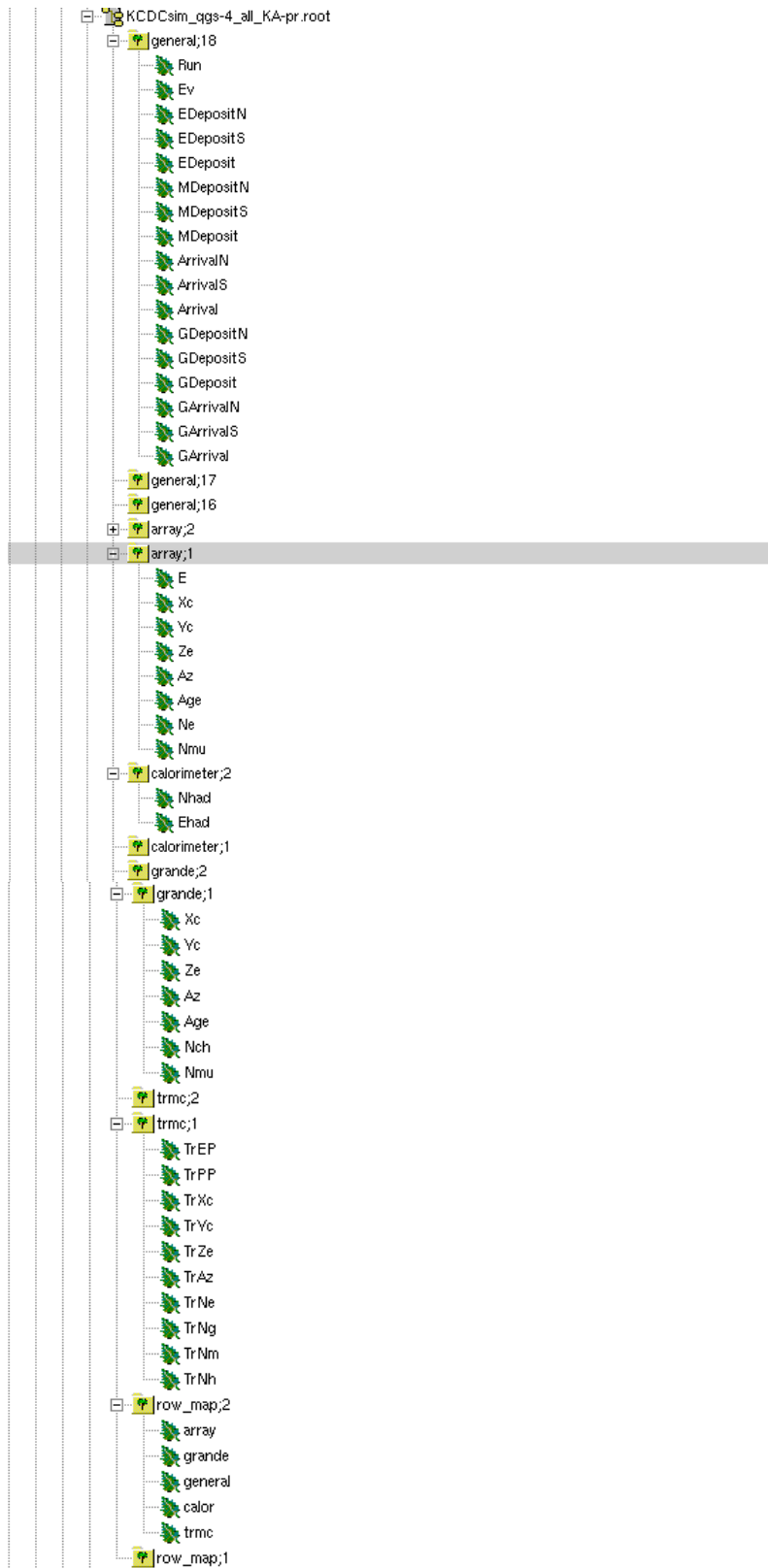


Fig. 9.1.1. *ROOT* -trees example for simulations with all quantities published

9.2 PROBLEMS WHILE HANDLING THE DATA FILES

9.2.1 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; //  
  :  
  :
```

9.2.2 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.

10 REFERENCE LIST

10.1 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

10.2 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

10.3 KASCADE-GRANDE

The KASCADE-Grande experiment

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

10.4 WEB –LINKS

For more information on KASCADE/KASCADE see:

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

For more information on KCDC see:

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

10.5 SIMULATIONS

GEANT: CERN report Brun R. et al., GEANT3 User Guide, CERN/DD/EE/84-1 (1987)

CORSIKA:

https://web.iap.kit.edu/corsika/physics_description/corsika_phys.pdf

<https://web.iap.kit.edu/corsika/usersguide/usersguide.pdf>

11 GLOSSARY

COMBINED We use the name **COMBINED** as a synonym for combined data analysis of the KASCADE and the GRANDE detector systems of the KASCADE-Grande experiment. The combined analysis merges the advantages of the formerly separated KASCADE and GRANDE analyses and leads to a consistent spectrum in the energy range 10^{15} to 10^{18} eV. The aim of the combined analysis was to utilize this improved reconstruction to get one single, consistent energy spectrum.

CORSIKA **CORSIKA** (**CO**smic **R**ay **S**imulations 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**stroparticle physics **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.

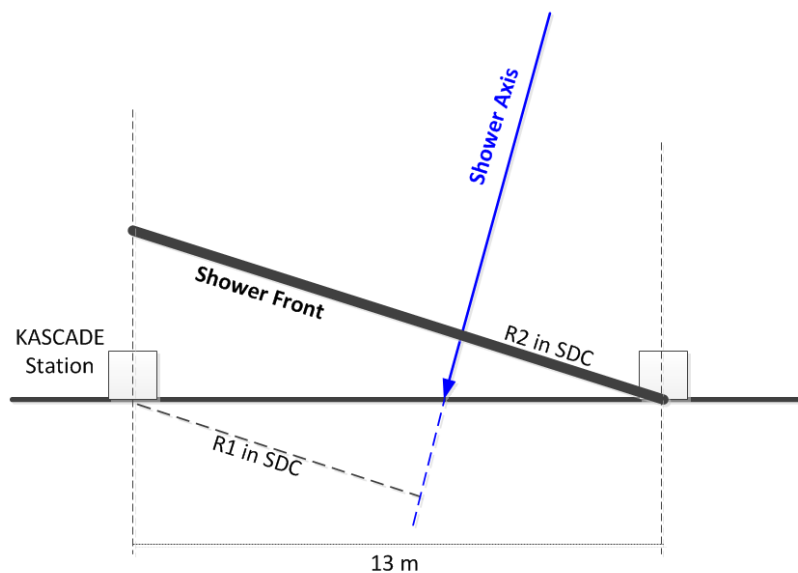
Glossary

KRETA (**K**ascade **R**econstruction of **E**xtensive **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 2 GeV). 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.

Quantity The KASCADE variables published in the KCDC web portal are called quantities

SDC **Shower Disc Coordinates**. The sketch below illustrates how the radii R1 and R2 are calculated in SDC.



Glossary

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.

12 APPENDIX

12.1 APPENDIX A – KASCADE STATION COORDINATES

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

Appendix

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

Appendix

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

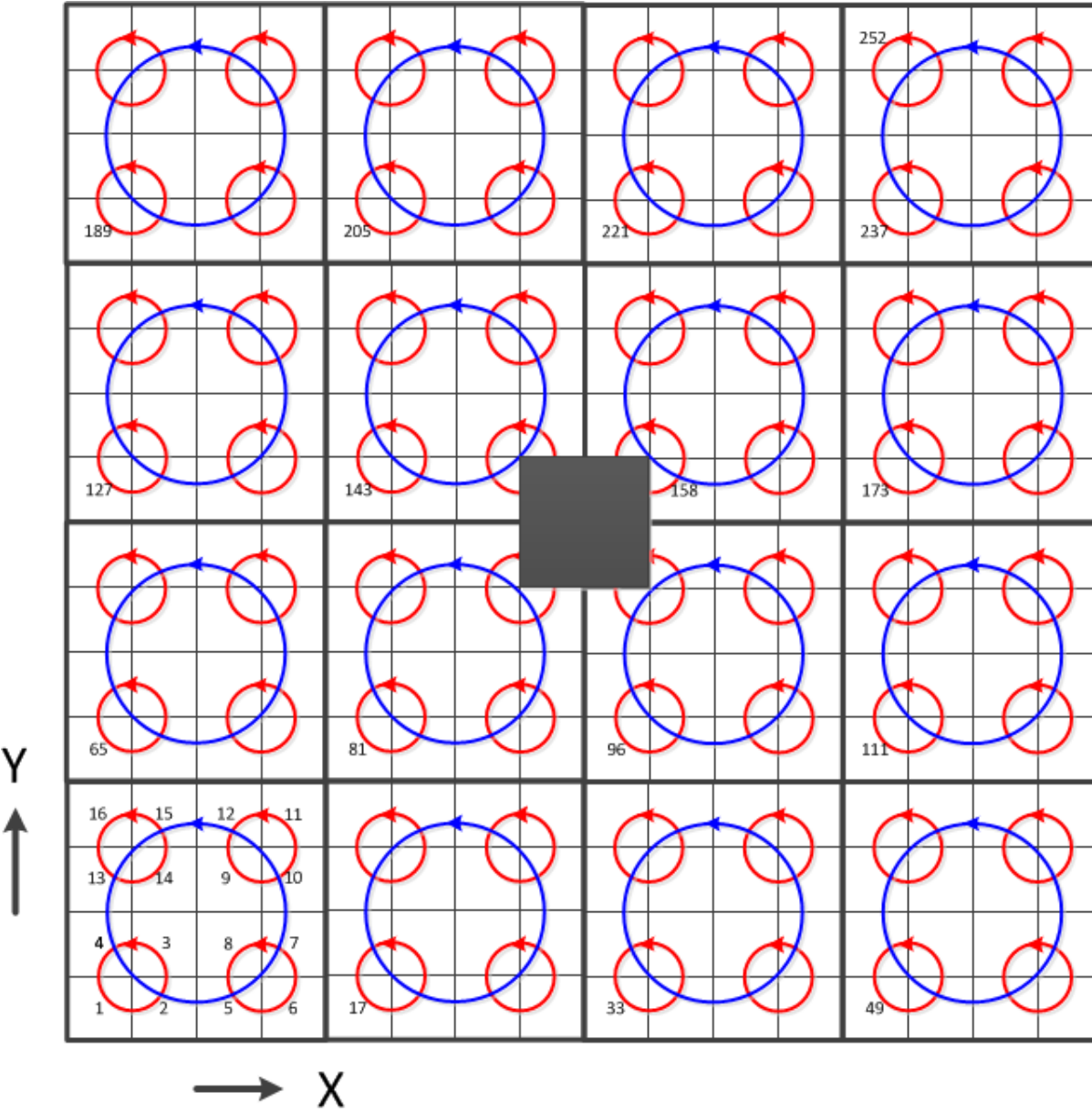


Fig. A.1 *The scheme of the counting of the array station IDs (1 ... 252)*

Python-code to fragment to calculate x- and y-positions from the station IDs

```

def get_station_locs():
    dstcl = 5200.           // width of array cluster [cm]
    dstqa = 2600.          // width of one sub-cluster [cm]
    dstas = 1300.          // distance between stations [cm]
    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

```

12.2 APPENDIX B – GRANDE STATION COORDINATES

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		

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

