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## Energy Spectrum and Elemental Composition in the PeV Region

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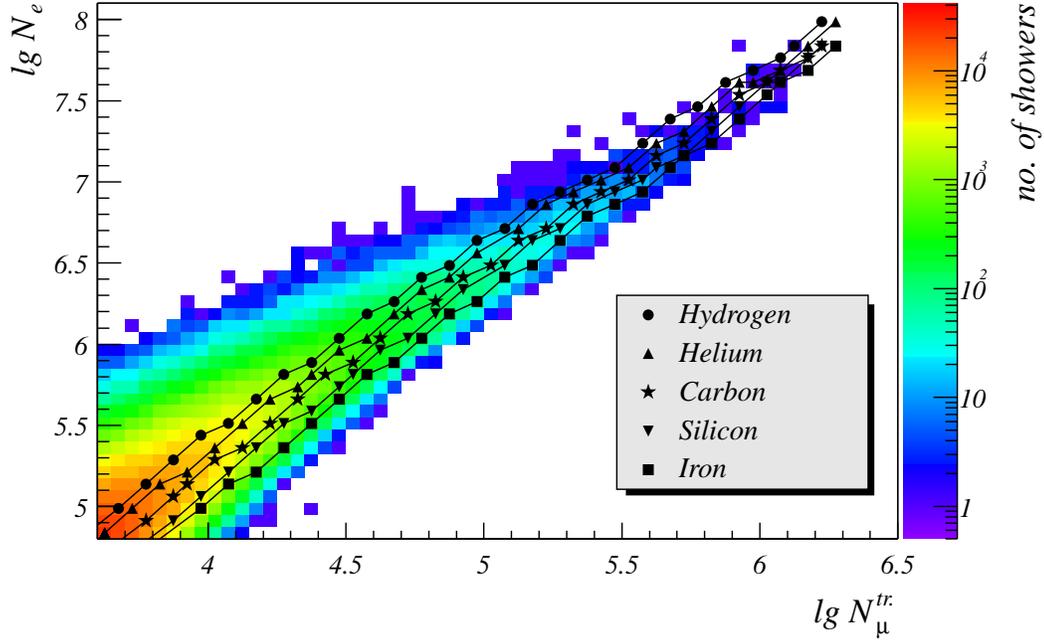
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### Abstract

One of the main aims of KASCADE is the determination of flux spectra for different primary cosmic ray mass groups to disentangle the knee feature. The field detector array of the KASCADE experiment measures the electron and muon component of extensive air showers in the knee region with high precision. On the basis of these measured data corresponding two-dimensional shower size spectra are investigated. On the arbitrary assumption that the chemical composition consists of five primary mass groups the size distributions are deconvoluted to reconstruct the energy spectra of the groups in the energy range between  $10^{15}$  eV and  $10^{17}$  eV. The energy spectrum results in a knee-like bending and a steepening above the knee. The topology of the individual knee positions suggests a rigidity dependence.

### 1. Introduction

The knowledge of the energy spectra of different components of primary cosmic rays in the knee region is of vital importance for testing alternative hypotheses of the cosmic ray (CR) origin and acceleration. The analysis of EAS presented benefits from the simultaneous measurement of different observables for each individual event by the KASCADE experiment [6]. Appropriate unfolding procedures, also taking correlations into account, make it possible to deconv-



**Fig. 1.** The two-dimensional shower size spectrum of  $\lg N_e$  and  $\lg N_\mu^{tr}$ . The zenith angle range of the showers is  $[0^\circ, 18^\circ]$ .

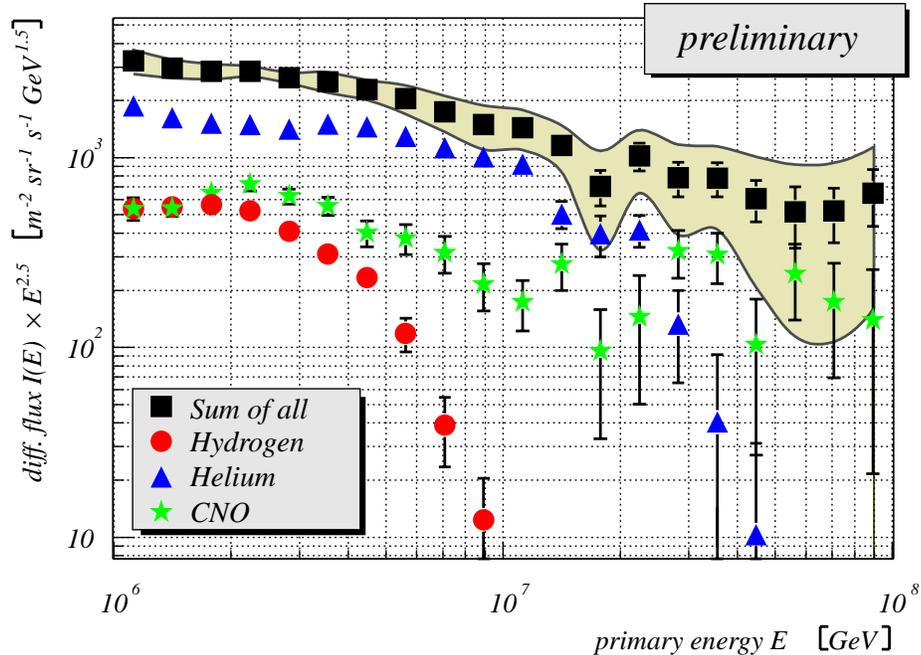
lute such multidimensional size distributions and result in energy spectra for five assumed primary mass groups represented by H, He, C, Si, and Fe.

## 2. Unfolding

In general the process of measuring distributions of physical observables  $g(\lg N_e, \lg N_\mu^{tr})$  (see Fig. 1) is often disturbed by inherent limitations which lead to the nontrivial problem of inferring true distributions from measured ones. Confining conditions like limited acceptance or efficiency of the detector arrangement, finite resolution, strong intrinsic fluctuations and parameter transformations have to be taken into account. Suitable methods to solve the inverse problem are unfolding algorithms based on *Fredholm integral equations of 1<sup>st</sup> kind*

$$g_i(\lg N_e, \lg N_\mu^{tr}) = \int_0^\infty t_i(\lg N_e, \lg N_\mu^{tr} | E) p_i(E) dE \quad (1)$$

where the transfer function  $t_i(\lg N_e, \lg N_\mu^{tr} | E)$  ( $i \in \{H, He, C, Si, Fe\}$ ) has to cover all the above mentioned limiting effects and is realized by means of detailed Monte Carlo (MC) calculations using the simulation code CORSIKA [4] and the hadronic interaction model QGSJet [5]. In the presented analysis  $t_i$  is dominated by the intrinsic shower fluctuations. Various variants of unfolding procedures exist to determine the energy distribution  $p_i(E)$  for different masses  $i$ . To crosscheck systematic uncertainties due to the method applied, KASCADE data are analysed

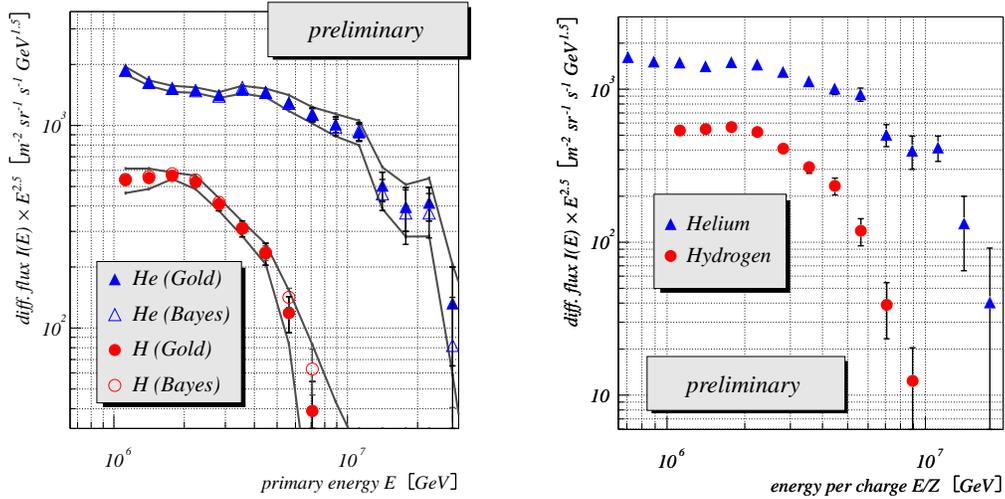


**Fig. 2.** Result of the Gold unfolding procedure. The given error bars reflect the statistical errors due to the measurement and simulation. The all-particle spectrum as well as the spectra for light elements are displayed. Systematic errors for the all-particle spectrum due to the applied method are indicated by the shaded area.

with conceptually different algorithms: in this paper the Bayesian approach [2,7] and Gold’s unfolding method [3,8].

### 3. Results and Conclusion

The resulting energy spectra applying Gold’s algorithm are shown in Fig. 2. Displayed error bars include statistical errors due to the measured and simulated number of events. In case of the all-particle spectrum the shaded area indicates the systematic uncertainty due to the method applied. The knee in the total energy spectrum at about 4 PeV is caused mostly by the steepening of spectra of light elements. The outcome of Gold’s unfolding algorithm is corroborated by the aforementioned Bayes unfolding as displayed in Fig. 3. The all particle spectrum agrees with previous KASCADE findings e.g. of a neural network analysis [1] as well. The position of the steepening of the spectrum is shifted to higher energies for heavier components. To investigate the energy dependence the spectra of H and He are shown as a function of rigidity  $R \propto E/Z$  in Fig. 4. As a preliminary result a rigidity dependent knee energy seems to be favoured by comparing the shape and the knee energy of the individual spectra. The study of limited MC sample size,  $(\lg N_e, \lg N_\mu)$  parameterisations, choice of representatives of different groups of elements etc. as major source of systematic uncertainties is in progress



**Fig. 3.** Comparison of the deconvoluted **Fig. 4.** Individual spectra as a function of the rigidity  $R \propto E/Z$ . The knee positions of the H and He spectra are nearly at the same position.

and is grossly estimated to be at least not less than 15%. In addition systematic studies with different other interaction models are necessary to exclude distortions from a specific model assumption. By using for example the QGSJet model the contribution of heavy elements is strongly suppressed as can be already estimated by the maximum position of  $t_i$  for different elements and energies indicated by the symbols in Fig. 1.

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