How Well Do We Know EAS Size Spectra?

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Abstract

Altogether 26 electron number or 'size' distributions of EAS in the knee region from 8 different experiments are analysed consistently and described by 5 fit parameters each. Whereas the knee positions show the expected exponential shifts with atmospheric depth considerable discrepancies become evident for some of the other parameters, notably the exponents of the powers laws far off the knee and overall intensities. Possible causes are discussed. Although no consistent explanation can be offered it is difficult to escape the conclusion that systematic differences between experiments are involved.

1. Introduction

Above ~ 1 PeV, attempts to determine energy and mass of primary cosmic ray nuclei rely on the observation of extensive air showers (EAS) and on the comparison of shower observables with simulations which try to model the cascade of interactions occurring in the atmosphere. These simulations are hampered by our incomplete knowledge of strong interactions. As a result different energy and mass distributions are obtained from the same observations if different interaction models are used for the simulations (cf. Ref. [6], e. g.). This is the more irritating because the differences of simulated distributions of observables calculated with different interaction models are not very large (cf. Refs. [6,10]). This may lead one to suspect that similarly small systematic differences between measurements might have a comparable impact on the results. It therefore appeared reasonable to study this aspect in more detail. Preliminary accounts of this study have been given previously [12,13].

2. Input data and fits

The experiments from which the spectra were taken are listed in the table. Each spectrum was fitted with a hyperbola by adjusting 5 parameters: knee position, exponents above and below the knee, overall intensity, and a parameter describing the smoothness of the knee. A hyperbola is, mathematically at least,

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a natural choice for a fit function which is asymptotically straight. The depth dependences of most of the parameters are displayed in Figs. 1 to 4.

Experiment	atmospheric depth $[g/cm^2]$	number of spectra	symbol in figs.	Ref.
Chacaltaya	551	1	o	[8]
Tibet	606	1	△	[14]
MAKET-ANI	731 - 949	4	▲	[3]
HEGRA	820	1	★	[7]
EAS-TOP	835 - 1040	6	□	[1]
CASA	883 - 1081	7	■	[4]
KASCADE	1047 - 1251	5	•	[5]
MSU	1068	1	◇	[9]

3. Results and discussion

The **knee positions** above ~ 750 $[g/cm^2]$ cluster along a straight line in the semilog plot of Fig. 1 as expected from the exponential decrease of shower size*. The two highest experiments deviate from this trend which is not surprising since EASs pass through a maximum during shower development. But the maximum inferred from Fig. 1, ~ 650 $[g/cm^2]$, is considerably deeper than simulations indicate†. The **exponents below the knee** γ_1 displayed in Fig. 2 deviate from each other, in some cases by more than 10 times their quoted statistical errors. Similar discrepancies are observed for the **exponents above the knee** γ_2 (Fig. 3) although here the errors are larger due to the poorer statistics of the observed spectra at higher shower sizes.

Concerning knee positions and exponents one has to realize that the size spectrum derives from the (concave) energy spectrum by folding it with a resolution function of finite width. This then results not only in a smoother bend but also in an upward shift of the knee position. The amount of this shift depends on the slope of the spectrum and on the resolution and hence on shower fluctuations and instrumental effects. It is straightforward to show that exponents are modified due to the dependence of resolution on size (or energy). So deviations as observed are not completely unexpected.

The **intensities** present a puzzle of their own (cf. Fig. 4). For the measurements deeper than ~ 700 $[g/cm^2]$ they scatter without strong trend, albeit by more than their statistical errors. But the values of the highest experiments,

*In all figures, errors are smaller than symbol size if no error bars can be seen.

†This was pointed out by A. A. Watson during the discussion following the presentation of Ref. [13].

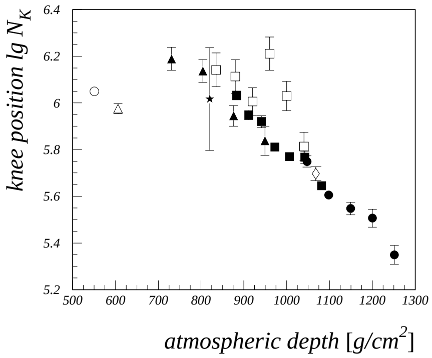

Fig. 1. Dependence of the derived knee position on atmospheric depth

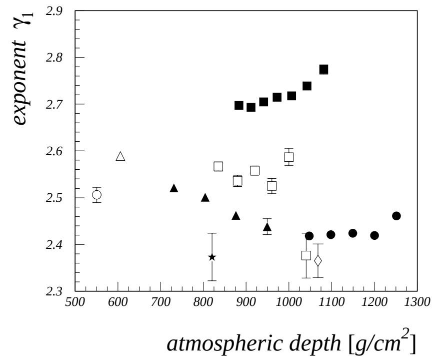

Fig. 2. Dependence of the derived exponents below the knee on atmospheric depth

Chacaltaya and Tibet, are larger by more than an order of magnitude. At least part of this discrepancy can be attributed to the fact that various primary masses contribute to the size spectrum. Deeper in the atmosphere, the size of an EAS induced by a heavy primary is smaller than that of a proton shower for the same energy. Hence heavy primaries are suppressed in the size spectrum. This does not hold near shower maximum where the electron number is not very sensitive to primary mass. It remains to be seen if this effect is sufficient to explain the large observed differences.

The **smoothness parameters** are only determined to moderate accuracy because only a few of the data points of each spectrum enter into their determination.

It is difficult to escape the conclusion that systematic differences are present between different experiments. At least some of these may be attributed to the influence of shower fluctuations as mentioned above. These should be expected to be accounted for by Monte Carlo simulations of shower development and detector response but may have been treated differently by the various experiments.

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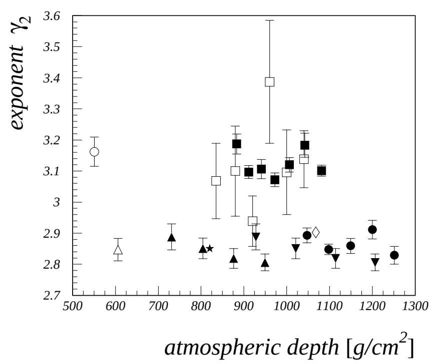

Fig. 3. Dependence of the derived exponents above the knee on atmospheric depth. The full triangles pointing downward represent the results of the Akeno experiment [11].

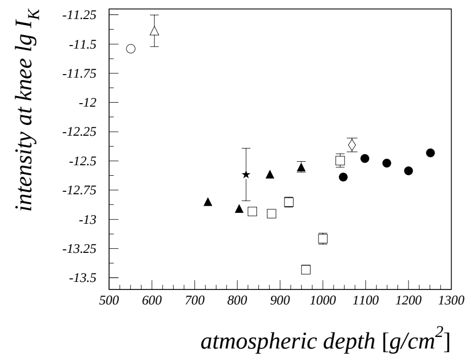

Fig. 4. Dependence of the derived overall intensities on atmospheric depth.

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