ELECTRON AND MUON PARAMETERS OF EAS AND THE
COMPOSITION OF PRIMARY COSMIC RAYS IN $10^{15} \sim 10^{17}$eV

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ABSTRACT

With a view to estimating the relative intensities of
protons and heavy nuclei in primary cosmic rays in the
energy region $10^{15} \sim 10^{17}$eV, a systematic comparison
has been made between all available observed data on
various parameters of EAS with the results of simulation.
The interaction model used is an extrapolation of
scaling violation indicated by recent $p\bar{p}$ collider
results. A composition consisting of various percentages
of Fe in an otherwise pure proton beam was assumed.
Greatest overall consistency between the data and the
simulation is found when the Fe fraction is in the region
of 25%.

1. Introduction   Direct measurements of the composition of the
primary cosmic ray beam have by now been extended to particle energies of
the order of 10^{14}eV. It seems clear however that above this energy only
indirect estimates will be available for a long time to come. These high
energies are however of the greatest astrophysical interest; the knee in
the primary spectrum at 3 10^{15}eV is already known for over a quarter of a
century yet its significance is still far from clear, whether it
represents a source feature, a propagation effect, a reflection of changes
in hadronic interactions or some combination of these. In particular
data from different types of experiments conflict so that, even in the
propagation effect scenario, it is problematical whether the knee at
3 10^{15} V represents the rigidity at which leakage effects start setting
in, or have already terminated [1]. The present report is confined to
the region above the knee, and attempts on the basis of an assumed model
for high energy interactions and reported measurements on various E.A.S.
parameters (excluding time profiles) to find a composition most consistent
with all the data. The basic approach is simple minded i.e. to add
varying amounts of Fe to an otherwise pure proton beam and compare the
characteristics of simulated showers with experiment.

2. Calculations   The model for hadronic interactions used incorporates
scaling violation [2] for the leading particle at energies greater than
210^{13}eV, and radial scaling for other distributions. The inelastic cross-
section for hadron collisions is assumed to increase with energy, and the
influence of the target air nuclei on inelasticity and multiplicity, as
evidenced by recent accelerator data, have been taken into account; more
details of the model can be found in paper HE4.3-12 at this conference.
We note that although this scaling violation model has been adopted as a
plausible, and consistent, framework for the calculations it is not
above criticism [3].

Three dimensional Monte Carlo simulations for proton and Fe

nucleus initiated events with primary energies in $10^{15} - 10^{17}$eV were carried out. Log-normal distributions in different quantities, with variances as determined by the simulations, and a primary differential spectrum of slope -3.0 were used to relate parameters at fixed shower size (as measured) with the simulations at fixed primary energy. In establishing longitudinal development profiles of electrons and muons when more than one primary species is present, for comparison with equi-intensity cuts, the approximate method described in paper HE4.3-12 was used.

The quantities investigated so far are the fluctuations in muon size $\sigma_{N\mu}/<N_\mu>$, N_μ vs. Ne correlations, electron longitudinal development, muon longitudinal development and lateral distribution. This roughly is the order of their sensitivity to primary composition; the ratio $\sigma_{N\mu}/<N_\mu>$ although it varies most is also however ambiguous in some regions, while the muon lateral distribution is almost independent of primary mass and will not be considered further here. The muon longitudinal development, as reflected in equi-intensity cuts is considered in greater detail in paper HE4.3-12 at this conference.

3. Results   The data on electron size equi-intensity cuts used were: Chacaltaya (550 gcm^{-2}) intensities 10^{-6}, 10^{-7}, 10^{-8}, $10^{-9}$and 10^{-10}m^{-2}, s^{-1} sr^{-1}. Tien Shan (690 gcm^{-2}) 10^{-6}, 10^{-7}, 10^{-8} and Akeno (930 gcm^{-2}) 10^{-6}, 10^{-7}, 10^{-8}, 10^{-9}, 10^{-10}. A comparison of these data with some results of the simulations (taking the coefficient in the integral primary
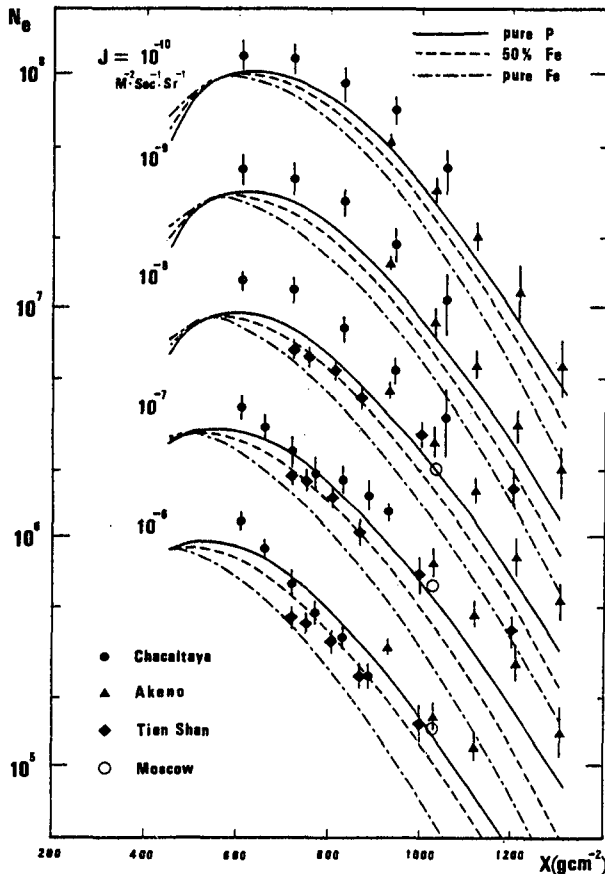

Fig.1 The longitudinal development of electrons from equi-intensity cuts for various compositions compared with observed points (A = 2.5$10^6$)

spectrum A = 2.5 10^6 [4]) are shown in fig.1. In the belief that the shape of the experimental curves may be more reliable than the determination of absolute sizes, a normalisation of the simulated curve i.e. a revision of A, to each experiment has been carried out by requiring the value of χ^2 (normalised), calculated using the data of the experiment and the simulated curve, to be a minimum (the variance in both the data and simulation results being allowed for). For each of the 3 experiments such minimum values of χ^2 have been obtained for each of 4 compositions i.e. pure protons, 25% Fe, 50% Fe and pure Fe.

Exactly the same procedure was carried out for the data on muon equi-intensity cuts: Chacaltaya at 10^{-8} and $10^{-9}m^{-2}s^{-1}sr^{-1}$, Tien Shan at 10^{-7} and 10^{-8} and Akeno 10^{-8} and 10^{-9}, each composition yielding 6 values of minimum χ^2 - some data are shown in fig.3 of paper HE4.3-12. Direct comparison was also made with N_μ vs Ne curves derived at Chacaltaya, Tien Shan, Akeno and Moscow - an example is shown in fig.2, and with the dependence of $\sigma_{N\mu}/<N_\mu>$ on shower size as determined at Tien Shan, Akeno and Moscow - the comparison with Akeno data is shown in fig.3. In this way 7 further χ^2 values are obtained for each composition.
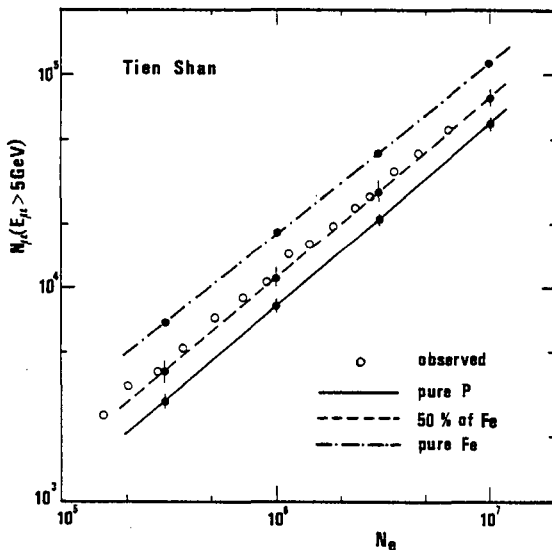

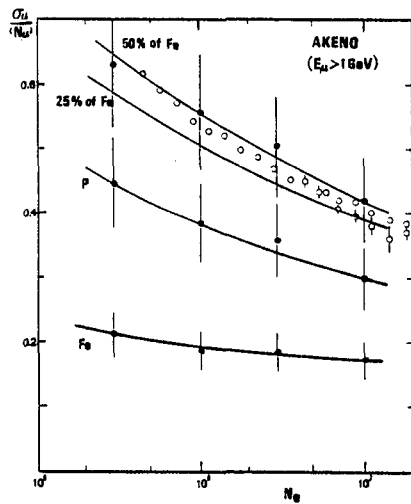Fig.2 Comparison of N_μ vs N_e data at Tien Shan [5] with simulations.

Fig.3 Muon size fluctuations at Akeno [6] compared with simulations.

The distributions in χ^2 for the four assumed compositions are shown in fig.4. The median values of χ^2 are given in the table. Generally the longitudinal developments favour very small admixtures of Fe, the major exception being the lowest energy Chacaltaya data - long known to be somewhat different; it is best fitted by a composition of pure Fe. The various N_μ vs N_e dependences as well as the muon

Composition	pure p	25%Fe	50%Fe	100%Fe
χ^2 median	0.96	0.62	0.82	7.51

fluctuations would generally favour somewhat more Fe. However, as the table indicates, when viewed overall a proportion of 25% is most favoured, if not very convincingly.

In the above considerations only the shapes of the equi-intensity curves were considered. If we turn to absolute values and take a coefficient A = 3.75 10^6 (cf. A = 2.5 10^6 in [4]) in the primary spectrum (this will lead to agreement between the electron size at shower maximum at J = $10^{-10}m^{-2}s^{-1}sr^{-1}$ at Chacaltaya, where least sensitivity to the nature of the primaries exists, see fig.1), consistency with muon longitudinal developments, for any composition, can only be obtained by assuming systematic errors in muon size determinations. These are not serious for Tien Shan or Akeno (in magnitude $\lesssim$ 20%) but for Chacaltaya suggests overestimates of muon size up to a factor of 2. Adjusting observed muon sizes to be consistent with the intensity, values of χ^2 were again obtained for N_μ vs N_e relations, and $\sigma_{N_\mu}/\langle N_\mu \rangle$. The general effect is to favour somewhat more Fe than 25% but the difference is not very great.

References

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Fig.4 χ^2/N distributions

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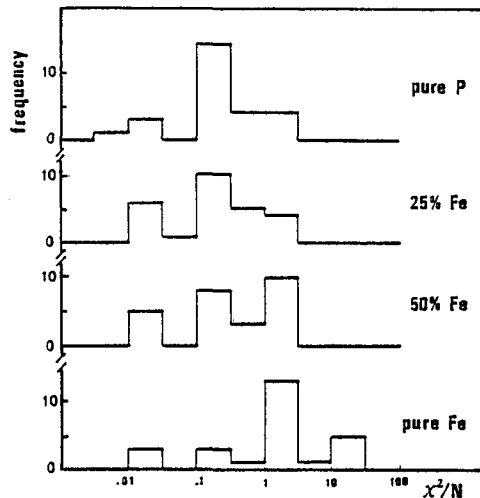[6] Hara T. et al., (1983) 18th Int. Conf. Cosmic Rays, Bangalore, Conference Papers, 11, 285-288.