THE PRIMARY COMPOSITION BEYOND 10^5 GeV AS DEDUCED FROM HIGH ENERGY HADRONS AND MUONS IN AIR SHOWERS

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ABSTRACT

We present data obtained from a large set of air shower simulation calculations using our highly refined hadronic interaction and shower simulation model, in an attempt to solve the problem of primary chemical composition beyond 10^5 GeV total energy. We discuss briefly that high energy hadrons in air showers offer a rather unique primary mass signature and show that the interpretation of high energy muon data is much more ambiguous. Our predictions are compared with experimental data where such data are available.

1. Introduction. The present work represents a search for observables and methods that would allow to identify unambiguously the mass group of a primary initiating a shower from either ground based or deep underground observations. We have shown in our early work (Grieder, 1977) that the significant information which requires the least number of simultaneous observables is to be found among the most energetic constituents of air showers. More recently we have shown that high energy hadrons in air showers observed at ground level offer a unique mass signature. We have also shown that these data in conjunction with experimental results indicate that the chemical composition beyond 10^5 GeV does not seem to change significantly from that at lower energies (Grieder, 1984).

In the following we summarize the results of our work on the relationship between high energy muons and primary mass for the energy range from 10^5 GeV to 10^8 GeV and compare these data with our previous results based on hadrons.

2. Model and Calculation. The present calculations are based on our two-component model for hadronic interactions which violates Feynman scaling in the central region and reproduces CERN pbar-p data very well. The calculations consider all significant particles and processes and include the electromagnetic component as well. The essential differences between proton and heavy primary initiated showers are due to the significant difference in the respective inelastic cross sections and in the high energy nuclear physics that governs the interactions. Both are considered in our calculations. For the nuclear physics aspects it is chiefly the fragmentation modi of the primary nuclei and, above all, the number of collision partners that are involved in nucleus - nucleus collisions that are problematic. There our current knowledge is still very marginal.

We have shown previously (Grieder, 1983) that it is chiefly this latter problem that troubles the interpretation of high energy muon data with respect to primary composition. In comparison to proton showers, it is the widely varying number of collision partners in the first few collisions of heavy primaries and their subsequent fragments with air nuclei that cause large fluctuations in the secondary particle multiplicity and in a number of other observables, such as the number of high energy muons per shower. In comparison to proton showers, the relative enhancement of muon production in heavy primary initiated showers resulting from the greater height of the first interaction and a lesser energy per nucleon diminishes with increasing primary energy because of the more rapid increase of the cross section for proton primaries in showers of comparable total energy, which rises the point of the first interaction of proton showers, thus stimulating muon production via pion decay. Furthermore, since the energy per nucleon of a proton primary is almost two orders of magnitude higher than that of an iron primary of comparable total energy, the central pion multiplicity is of comparable order of magnitude or larger than the combined multiplicity of fragmentation region pions from all first generation collisions of nucleons from iron nuclei and their fragments.

3. Results and Conclusions. In the following we are presenting a set of muon data from our recent all-component calculations. The data are shown in figures 1a) to 1f) and cover a range from 10^5 to 10^8 GeV total primary energy, for proton and iron initiated showers. It was assumed that 10 nucleons of the primary nucleus interact in each of the first iron initiated interactions. Total fragmentation of the nucleus was assumed to occur in the first interaction. Other break-up modi have also been investigated, with the result that distinction between iron and proton showers was even less, as expected.

For low energy muons the well known picture envolves which shows an increase of the muon number with primary energy that goes as energy to power 0.8, with the usual enhancement factor of about 2 or more for iron showers (c. f. figure 1a). However, for muon energies in excess of 100 GeV, relativistic effects in conjunction with the energy and mass dependence of cross sections change the trivial relationship at high primary energy. This becomes evident upon inspection of figures 1b) through 1f). The cross-over of the two curves depends on muon energy, of course, as shown in figures 1d), 1e) and 1f).

Because of the multiplicity law on one hand and the competition between interaction and decay of pions as a function of energy on the other, it is evident that pions from different rapidity regions are responsible for muons of a given energy group resulting from either proton or iron initiated showers of the same total primary energy. These facts in conjunction with the above mentioned high energy nuclear physics aspects govern the muon number in a particular energy group in proton or iron initiated showers.

From the above considerations it is evident that a given muon detector, located at a particular depth underground, corresponding to a certain energy cut off is only suitable for investigating a distinct primary energy range with respect to chemical composition. Moreover, because of the remaining ambiguities, data from at least two or more underground detectors located at different depths will be required to get a unique answer. Upon folding of the known primary energy spectrum with the multi muon rates, a coarse mass determination can be achieved, provided that the detectors cover an adequate area. Present underground installations are still marginal in size for reliable multi muon detection. This point is discussed elsewhere (Grieder, HE 5.4-4, this conference).

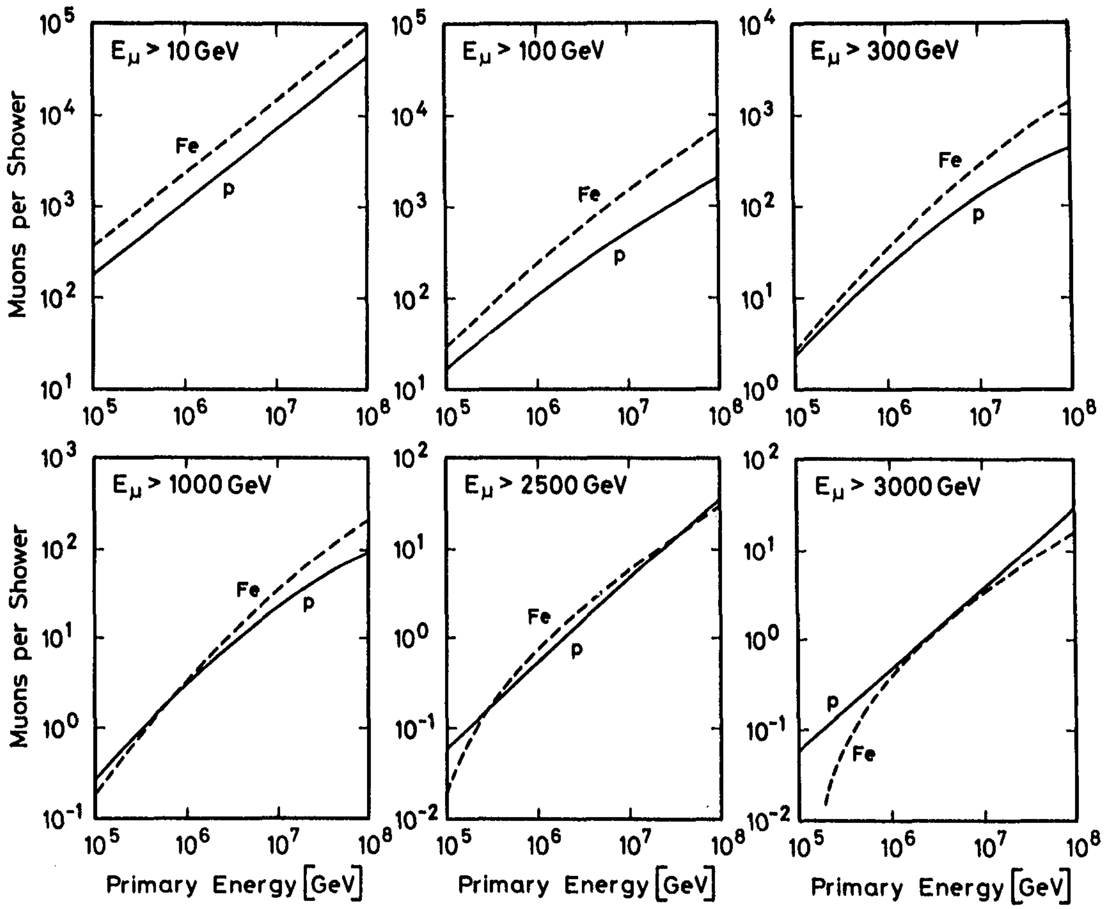

Fig. 1 Muon number versus primary energy in proton and iron initiated showers for different muon cut off energies, as specified.

At lower muon energies experimentally observed correlations between muon number and primary energy (or shower size) have so far failed to manifest an unambiguous transition from a so-called normal to an iron rich composition at the expected location in the primary spectrum, as is shown in figure 2. Thus we also conclude from these data that the composition is more likely to change little if at all, and that the bend in the spectrum is due to another cause.

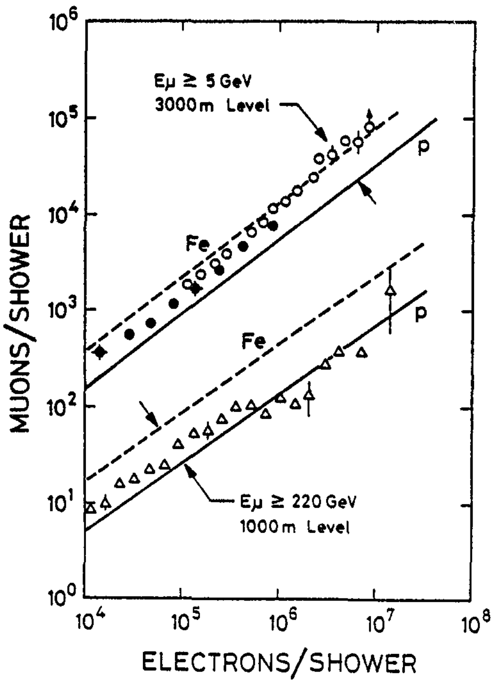

Fig. 2 Muon - electron correlations for proton and iron initiated showers. The dashed and solid lines are from our calculations. The full and open circels are experimental data from Tien Shan (Kabanova et al., 1973 and Machavariani et al., 1979), the triangular symbols from the Kolar Gold Fields (Acharya et al., 1983).

Lack of space does not allow us to summarize the hadron data here. For details on this topic the reader is referred to the earlier mentioned reference (Grieder, 1984). In spite of the fact that hadrons offer theoretically a more clearcut primary mass signature than muons, we fully realize that high energy muons have their experimental merits.

4. Acknowledgements. We are grateful to the Swiss National Science Foundation for supporting this project.

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