ON THE DETECTION OF HEAVY PRIMARIES ABOVE 10^{14} EV

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Knowledge of the chemical composition is fundamental to understanding the origin, acceleration and propagation of cosmic rays. At energies much above 10^{14} eV, however, the detection of single primary cosmic rays is at present impossible because of their low flux, and the only source of information is from the cascades initiated by energetic primary particles in the atmosphere--the extensive air showers (EAS). A similar situation exists for the study of hadronic interactions above 10^{15} eV. A recent EAS experiment (Goodman et al., 1979) suggests the possibility that the spectrum becomes increasingly rich in heavy nuclei as the total energy per nucleus approaches 10^{15} eV. Above that energy the overall spectrum steepens and the question of composition is almost completely open.

New air shower experiments, such as the University of Durham fast-timing Cerenkov array (Orford and Turver, 1976), the Soviet air Cerenkov experiment of Khristiansen et al. (1979), and the Utah Fly's Eye (Cassiday et al., 1978), show great promise for obtaining rather direct information both about the properties of hadronic cross sections and about composition at 10^{17}-10^{18} eV (and even higher in the case of Fly's Eye). These techniques map longitudinal development, including the early stages, of individual showers. Even for these experiments, however, interpretation is not straightforward because the actual beginning of the shower cannot be seen. In the case of Fly's Eye, for example, it has been proposed that the atmospheric depth at which the shower reaches 1/4 maximum ($y_{1/4}$) be used as a measure of the depth of shower initiation. Simulations will thus continue to be essential to interpretation of EAS experiments. Particularly important in this context is a proper treatment of nuclear breakup and especially of pion production in nucleus-nucleus collisions.

Following Dixon, Turver and Waddington (1974) our strategy is to use real interactions of nuclei at moderate energies (10 GeV/nucleon) as the basis of an extrapolation to EAS energies. We assume that the fragmentation probabilities are independent of interaction energy and depend only on the nature of projectile and target nuclei. In a Monte Carlo approach this enables us to choose fragmentation histories from the sample of real events. Direct use of the data is inadequate for pion production because

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of its known energy dependence. Instead we reduce each nucleus-nucleus collision to an equivalent number of nucleon-nucleon collisions. This enables one to use the energy-dependence implied by one's favorite model of nucleon-nucleon collisions. The number of nucleon-nucleon collisions is related to the type of fragmentation by giving each released nucleon a certain probability of interacting to produce pions. The fraction C_1 of unbound nucleons that interact can be estimated from data by comparing the multiplicity of charged mesons per released nucleon with the multiplicity in pp collisions in the appropriate energy range. We find C_1 decreasing from 0.4 for Z = 8-10 to 0.1 for Z = 26.

As an illustrative example of the use of these results we have compared the average and the standard deviation in depth of maximum (y_{max}) and in $y_{1/4}$ for the superposition model and for the model described above. In both cases the same Monte Carlo program was used to generate subshowers from individual nucleon-nucleon collisions. In the realistic model fluctuations in $y_{1/4}$ are about twice as big as for superposition and are comparable to the separation between $\langle y_{1/4} \rangle$ for adjacent mass groups, a circumstance which may complicate the analysis of the experiments mentioned at the beginning.

These considerations are also relevant to experiments with thin calorimeters in which the primary charge can be measured directly but in which not all the energy is deposited in the calorimeter. Fluctuations in early cascade development due to nuclear breakup will contribute to fluctuations in the relation between E(total) and E(visible) for primaries with $Z > 1$. We have in mind the Japanese-American emulsion chamber collaboration (Jones et al., 1980).

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