HIGH ENERGY HADRONS IN EXTENSIVE AIR SHOWERS

S.C. Tonwar

Tata Institute of Fundamental Research
Homi Bhabha Marg, Colaba, Bombay-400 005
India

ABSTRACT

Experimental data on the high energy hadronic component in extensive air showers of energies $\sim 10^{14}$- 10^{16} eV, when compared with exp--ectations from Monte Carlo simulations have shown the observed showers to be deficient in high energy hadrons relative to simulated showers. We attempt here to understand these anomalous features with more accurate comparison of observations with expectations, taking into account the details of the experimental system. Results obtained from this analysis and their implications for the high energy physics of particle interactions at energies $\sim 10^{15}$ eV are presented.

Studies on the characteristics of particle interactions at energies above those available at particle accelerators are being carried out either with emulsion chambers at mountain altitudes or through experiments on the high energy hadron component in extensive air showers. Results obtained on the hadron component in air showers of energies $\sim$ 10^{14} - 10^{16} eV over the last 15 years or so have presented a baffling picture. Initial attempts to interpret the observed characteristics of high energy hadron component in EAS were undermined by the apparent large differences between the results reported by different groups. However, during the last few years, our group[1,2] has been able to show that these differences are mostly due to instrumental factors and there indeed is a basic disagreement between the experimental results and the expectations from Monte Carlo simulations which use data available from CERN $\bar{P}P$ experiments. These disagreements relate to (i) the number of high energy hadrons per shower and(ii) the charged to neutral ratio among these hadrons. The present situation regarding the comparison between experimental results from four groups and our simulations[1] is shown in figure 1. It is seen from this figure that the most accurate measurements (represented by the line RHV) made using multiplate cloud chamber show the observed number of hadrons in a shower to be almost an order of magnitude smaller than the expected number. Electronic detectors (like single layer scintillators used as burst detectors), which integrate partially the energies of hadrons incident over the hadron detector, represented by lines RVS and BVS, expectedly overestimate the number compared to the measurements made with multiplate cloud chamber. Large area hadron calorimeters which integrate over the energies of the

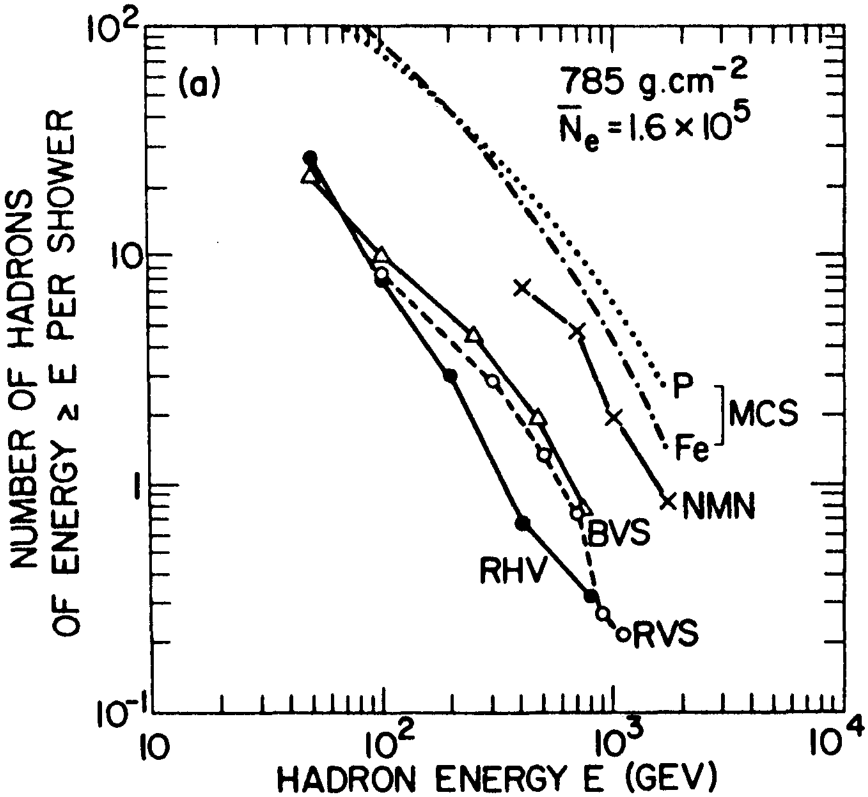

Figure 1 : Comparison of the observed integral energy spectrum for high energy hadrons in air showers of average size $\sim 1.6 \times 10^5$ at mountain altitudes (from reference 1)

hadrons incident over the detector fully, represented by the line NMN, give a much larger number for the high energy hadrons as expected.

It is clear from figure 1 that some major changes are required in interaction model at energies $\sim 10^6$ GeV to account for this large discrepancy. A constraint on the range of models that can be proposed to account for this discrepancy is imposed by the observed charged to neutral ratio[2] for these high energy hadrons at mountain altitudes as shown in figure 2. It is seen from this figure that the observed C/N ratio is less than half of the value expected from simula--tions. Since charged pions constitute the largest component of the charged hadrons, protons and charged kaons being much smaller in number and neutrons and neutral kaons constitute most of the neutral hadrons, the results fron C/N ratio suggest that dominance of pions among secondary particles may be less in interactions at air shower energies. Of course, another cosntraint on the range of models is imposed by the fact that observations on electron and muon components in air showers seem to agree well with expectations[3]. It should be remarked here that our lack of firm knowledge of primary composition at air shower energies which plays a very significant role in interpretation of observations on electron and muon components, does not have any important role in the interpretation of data on high energy hadrons. It should also be noted that the discrepancies discussed above cannot be accounted in terms of experimental factors , e.g energy resolution etc. The parameters that

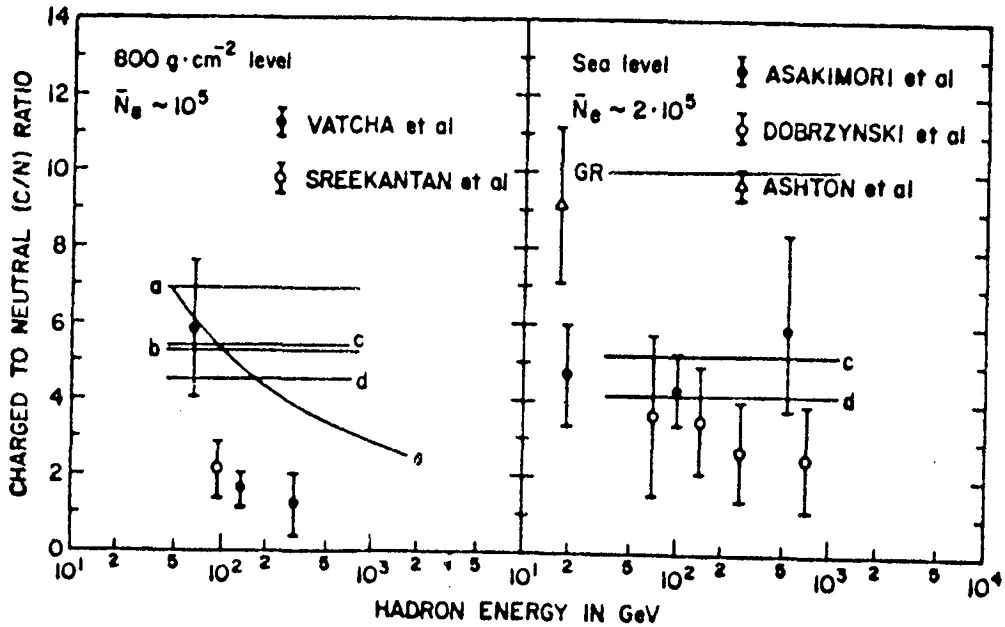

Figure 2: Comparison of the observed charged to neutral (C/N) ratio with expectations from simulations as a function of the hadron energy (from reference 2)

are readily available for changing the interaction model, without invoking an altogether new type of interaction such as suggested by the observat--ations[4] of Chirons, Geminions, and Centauros, etc. type of events in emulsion chamber experiments at mountain altitudes, are (i) interaction cross-sections, (ii) composition of secondary particles, (iii) transverse momentum distributions, and (iv) longitudinal momentum distributions. Note that the average multiplicity as well as its distribution are essentially controlled by the forms of distributions for (iii) and (iv). The simulations already incorporate the increase in cross-sections[5] consistent with observations upto $\bar{P}P$ Collider energies and in fact are consistent with observations upto the highest energies $\sim 10^{18}$ eV. Changing the composition of secondary particles towards lowering the pion content among secondaries and increasing the baryon content helps in reducing the C/N ratio but does not reduce the expected number of high energy hadrons significantly. The fact that large p_t tail and jets seem to play an important role at very high energies has already been incorporated in the calculations, though not specifically as jets but as an energy dependent component of large p_t particles. It may also be noted here that consistency of the observed lateral distribution of hadrons with simulations approximately, poses some restraints on the range of large p_t cross-section that can be assumed. Softer x distribution is being tried in simulations at present and analysis is being carried out of showers simulated with various assumptions. Progress in this work will be discussed at the Conference.

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