ELECTRONS, MUONS AND HADRONS IN EXTENSIVE AIR SHOWERS AND HOW DO THEY DEPEND ON NUCLEAR INTERACTION MODEL
(Part I)

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We performed Monte Carlo simulations of extensive air showers, using a couple of different nuclear interaction models and obtaining a variety of shower characteristics. The discussion of these shows, that the sensitivity of observables to the primary mass spectrum is significantly stronger than to the interaction model, the latter being quite weak.

The interpretation of cosmic ray observation carried out at various depths in the atmosphere requires detailed simulations of the propagation of nuclear-electromagnetic cascades generated by primary cosmic rays in the atmosphere. These calculations demand quantitative prescription for the following inputs necessary to carry out the simulation:

1. Chemical composition and energy spectrum of primary cosmic rays beyond where direct measurements were made (>50 TeV/nucleus);
2. Inclusive cross-sections for particle production in hadron-air nucleus collision at high energies - beyond (and not only, cf [1]) those available at SPS pp and Tevatron II;
3. High energy nucleus-nucleus cross-sections and fragmentation properties.

In addition, photons and electrons produced in the simulation tree must be propagated down to earth using electromagnetic theory and semi-empirical distribution functions. Thus the simulation is complex, multivariate enterprise. Quite often it is difficult to intercompare results from simulations of different groups because of not only disparity of the input,

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but also due to the simulation structure and algorithms.

In this paper together with HE 4.1-2 in this volume (see also [1]) we examine the sensitivity of air shower observations to changes in the interaction model and the nature of the primary by carrying out rather complete simulations over a wide energy range using the same program structure for shower generation, but changing the parameters, mostly one at a time, in the interaction models, for both proton and iron primaries. The energy range covered is from 20 TeV to 1 EeV (10**18eV). The interaction models vary from one with constant cross-section and scale invariant production distributions to a model with rapidly rising cross-section, large violation of scaling in both forward and central regions and charge exchange for the leading particle.

Nuclear interaction models

Particle production distributions in p-air and meson-air collisions are approximated by p-p and meson-p collisions. Two basic models of our variety are briefly compared in Table 1; the corresponding inclusive cross-sections are shown in Figs.1 and 2.

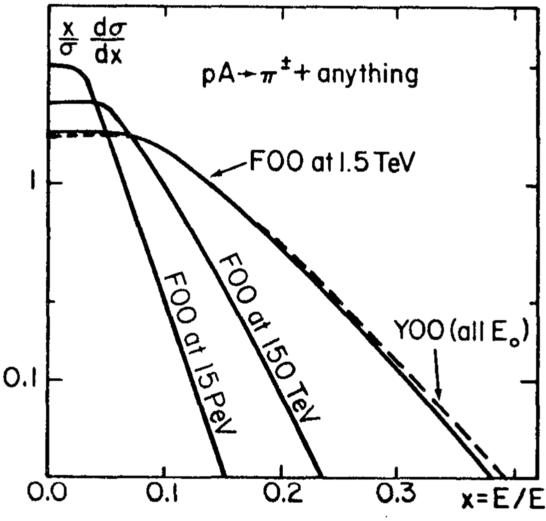

Fig.1. The distributions of x=E/E[int] for models used in our study.

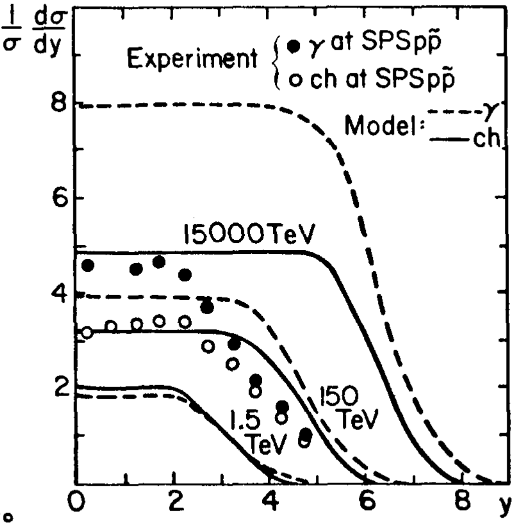

Fig.2. The rapidity distributions compared with pseudorapidity data from SPSpp.

Some other models were tried out, too, in order to check effects due to some particular differences in the assumptions:

* M-Y00 - same as F-Y00, but the cross-sections in hadron-air interactions rise as in M-F00 (this is what the M before the hyphen means),

- * M-F01 - adding a possibility of charge exchange to M-F00: interacting pion emerges from the collision with equal probabilities in any of three possible isospin states, and a kaon - in any of the four (the charge exchange possibility is denoted with the last "1" in the model notation),

- * R-F01 - similar to M-F01, but with faster rise in cross sections: mean free paths for nucleons decrease in "M" case from 84 .to 55 g/cm^2, and in "R" - from 86 to 37 g/cm^2 between 1 TeV and 1 EeV.

Table 1 Comparison of features of two basic models used.

	Model F-Y00	Model M-F00
Mean free paths for inelastic interaction	Energy-independent: nucleons: 75 g/cm^2 pions: 110 g/cm^2 kaons: 130 g/cm^2	Below 1 TeV nucleons: 84 g/cm^2 pions,kaons: 117 g/cm^2 Above 1 TeV $L(E) = L_0/(1+.0383*\mathrm{Ln}\ E)$
Inelasticity	Uniform in (0,1) for nucleons and (1/3,1) for mesons	
Inclusive distributions in x = E/E[interaction] for secondaries	Energy-independent: scaling extrapolation of the ISR data	Below 1 TeV as Y00; above: the functional shape is unchanged, but the scale x-value decreases as $1/E[\mathrm{int}]^{.125}$
Secondaries produced	Charged pions - 60% Neutral pions - 30% Charged kaons - 5% Neutral kaons - 5%	Below 1 TeV as Y00; above: the fractions of kaons and neutral pions increase with energy, reaching at 1EeV 6.8% (each) and 53.7%, respectively
Charge exchange of an interacting meson	None (i.e. the leading particle emerging from the interaction is always identical in kind to the interacting one)	
Transverse momenta	See [3]; irrelevant here, as we present only longitudinal EAS properties	

Nucleus-Nucleus interactions

For nuclei other than protons the interaction cross-sections had to be assumed, as well as some nucleus interaction/fragmentation model. Once again, the detailed description of the fragmentation algorithm may be found in [3]; it is based on the data compiled in [4] by J.E.Nowicka et al. The mean free paths for nucleus-air interaction were assumed in two different ways:

@ Energy-independent values [4] ranging from 37 g/cm^2 (alpha particles) to 16 g/cm^2 (iron). These were used for heavy nuclei-initiated EAS generated with model F-Y00, therefore denoted as FF-Y00;

@ R - rising cross-sections in Gaisser parametrization [2], consistent with "R" pA ones, e.g. for the iron group the mean free paths decrease from 12.2 to 10.6 g/cm^2 between 100 TeV and 1 EeV. These were used in combination with "M-" or "R-" models, therefore denoted as e.g. RM-F00 or RR-F01.

Other simulation assumptions

For hadrons and muons three-dimensional Monte-Carlo simulation was performed down to the threshold energy of 2 GeV (1 GeV for of pi-zeros). Photons and electrons emerging in the simulation tree were accounted for down to 170 MeV. However, the electromagnetic showers were followed the Monte-Carlo way only to a 200 GeV threshold; as soon as a photon or electron reached energy between 170 MeV and 200 GeV, the number of cascade electrons due to it was estimated from the Greissen formula. [This approach is more exact, than a non-Monte-Carlo treating of each electromagnetic shower from the very beginning].

The assumed cascade unit was 36.7 g/cm^2 and the critical energy - 84.2 MeV. (The c.u. value turned out to be quite important; changing it by just 1 g/cm^2 results in 6-7% change in 200 TeV shower sizes at sea level!). In the high-energy part (i.e.above 200 GeV) only pair creation, bremmstrahlung and Coulomb scattering were included into simulation.

As far as the main aim of this work was to check the model sensitivity, we limit this presentation to only vertical showers in the U.S.Standard atmosphere; the detection level was at the depth of 1000 g/cm^2.

Above 1 PeV initial energy, the thinning technique invented by Hillas [5] was used (to save the CPU time); performed checks proved, that this did not affect either the average values or the width of fluctuations (at least those checked by us).

The review of results obtained as described here may be found in our contribution HE 4.1-2 to this Conference.

References

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