THEORETICAL STUDY OF EAS HADRONIC STRUCTURE

L. Popova
Institute of Nuclear Research and Nuclear Energy
Bld. Lenin 72, Sofia, Bulgaria

<u>1. General remarks on the experimental data</u> The structure of EAS is determined mainly by the energetic hadrons. They are strongly collimated in the core of the shower and essential difficulties are encountered for resolution of individual hadrons. The properties for resolution are different of the variety of hadron detectors used in EAS experiments. This is the main reason making it difficult to obtain a general agreement between actually registered data with different detectors.

The most plausible source for disagreement is the uncertainity in determination of the energy of individual hadrons. A principal factor might be the incidence of multiple hadrons over large area detectors. Such measurements do not distinguish between events with one or more hadrons over the detectors and thus, provide an upper limit to the hadron energy flow /1/. For example, hadron measurements in Kolar Gold Fields /2/ performed with a deep iron calorimeter, include leakage of energy flow in the energetic electron component which arrives through the top layers and, particularly, through the sides of the calorimeter for inclined showers. This is valid, to a lesser extent for the measurements at Tian Shan /3,4,5/ performed with smaller ionisating detector. The measurements at Pic du Midi /6/ with flash tube hodoscope were relatively less affected due to the thickness of the detectors. In the scintillator burst detectors, distortion in hadron energy due to multiple hadron incidence is expected to play a significant role even though the individual scintillators occupy relatively small area as in the case of Norikura experiment /7/.

Many efforts during the last few years were devoted to estimation of the effect from multihadron incidence /8/. The signals observed in Ooty experiment /8/ with burst detectors were converted /9/ to hadron energy using conversion factor obtained with Monte Carlo simulations /1/. There was pointed out a reasonably good agreement between the results in Ooty experiment, and those from Pic du Midi /6/. Nevertheless, significant difference is observed with the calorimeter measurements /2,3/. This situation is shown in fig.1 and 2, where we compared the experimental data of hadrons in EAS at different levels. All data are normalized assuming that the attenuation length of hadrons is 350 $g.cm^{-2}$ /5/.

<u>2. Analysis of the model calculations</u> In the begining we want to point out an unespected effect revealed from the theoretical investigations, e.g. the change in the assumptions about the main parameters of high energy interactions, as well as for the nature of the primary particles, are relatively slightly affecting the properties of hadronic component in EAS at mountain altitudes. For example, the lateral distribution of hadrons (E_h>300 Gev) calculated by us on the basis of our new phenomenological model /10/, in which is assumed breaked scaling variable $x_s = x.\sqrt{s}^{\omega}$, is very similar to that

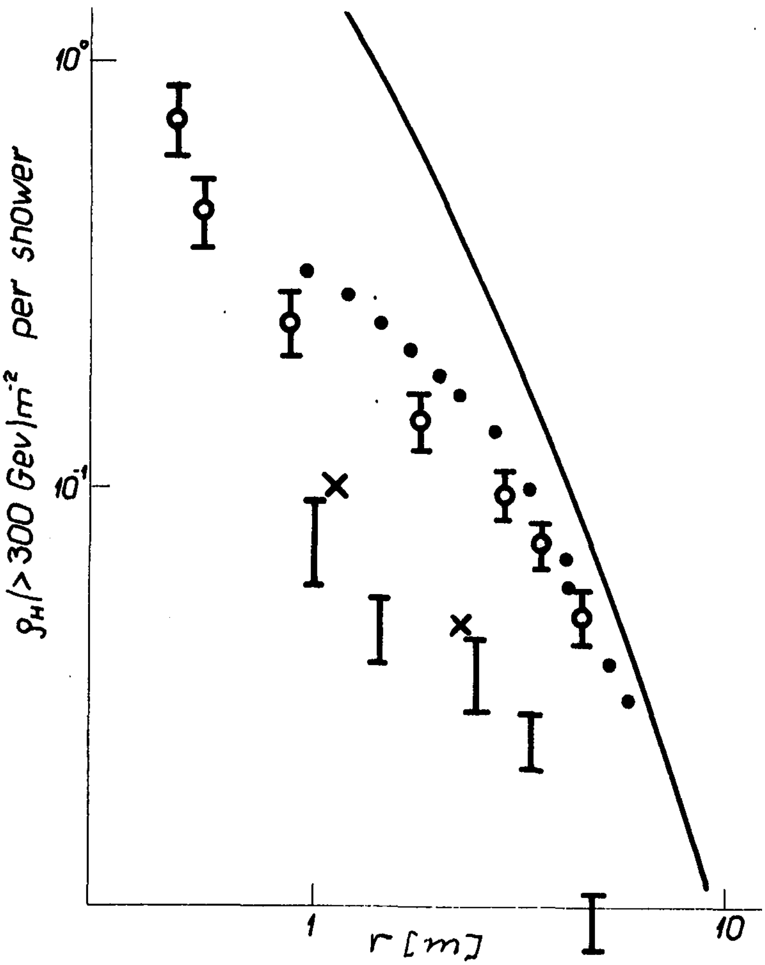

Fig.1 Lateral distribution of hadrons 300 Gev in EAS falling at mountain altitudes with intensity 1.6 10-5 $m^{-2}s^{-1}sr^{-1}$
- Tian Shan data/3-5/
- Kollar Gold Fields data/2/
- × Pic du Midi data/6/
- I Ooty burst data/9/

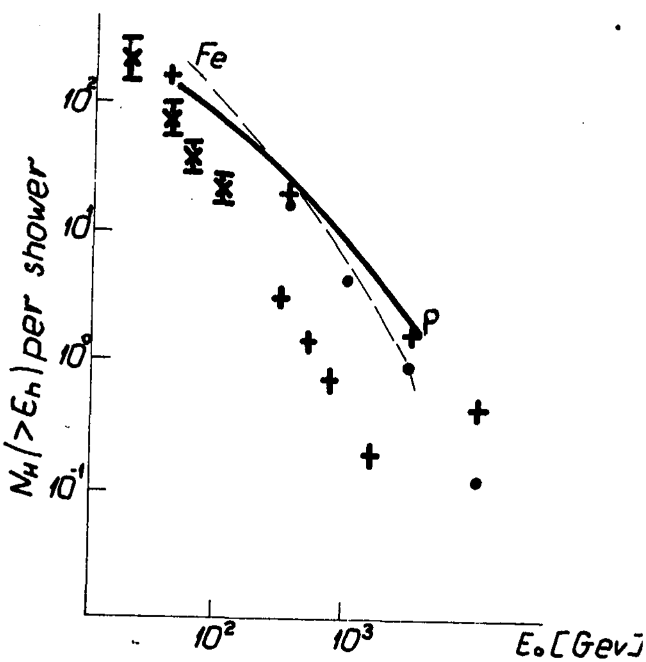

Fig.2 Energy spectrum of hadrons at mountain altitudes in EAS with intensity $10^{-5}\ m^{-2}s^{-1}sr^{-1}$.
- • Tian Shan data/3,4/
- + Kolar Gold Fields data/2/
- Norikura data/7/
- Pic du Midi data/6/
- —— present calculations for proton showers,
- – – present calculations for iron primaries.

obtained by Grieder/11/ assuming standard model with multiplicity $n_s \sim E^{0.437}$ in the both extreme cases of proton and iron primary spectrum. Similar small effect from the change of interaction models on EAS hadrons with different energies and in wide range of shower sizes is observed in comparing our breaked scaling model calculations with those of Kempa/12/ assuming standard model with different multiplicity laws ($n_s \sim E^{1/4}$ and $n_s \sim E^{1/2}$). All those facts are showing that in general, the number of hadrons at mountain altitudes is not very sensitive to the change of multiplicity law.

By means of the results obtained recently by Sreekantan et al/9/ with similar breaked scaling model we can see in fig.3 the influence of the assumption about the energy spectrum of the secondary particles, characterized by the scaling violation parameter α. They have assumed slight increase of α that equalizes our parameter ($\alpha = 0.13$ in Lab. system) at energies about 2.10^5 Gev. The steeper shape of curve 2 can be connected with the larger coefficient of inelasticity (0.72) in pion collisions assumed by Sreekantan et al.

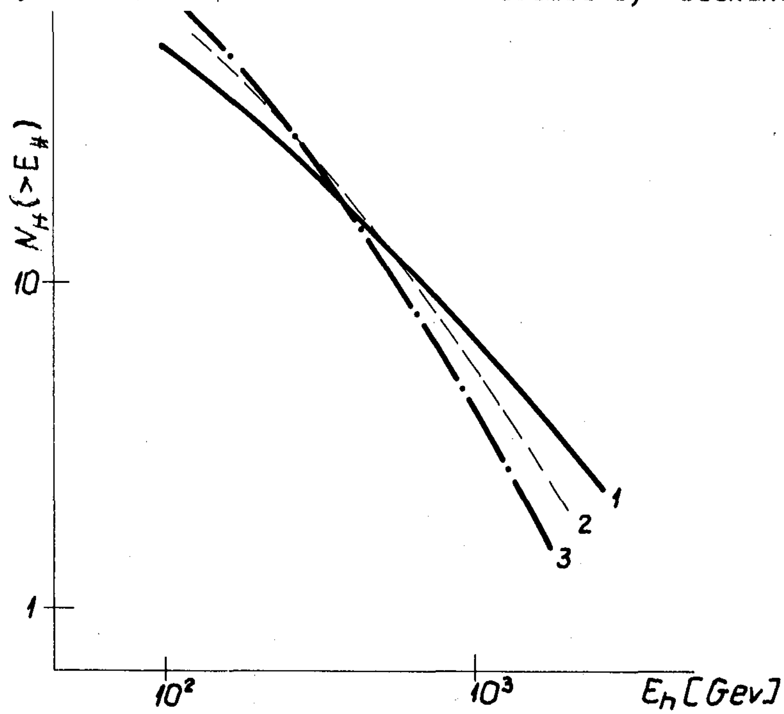

Fig.3 Comparison of the theoretical predictions for the energy spectrum of hadrons in EAS with size $1.5\ 10^5$ at 785 g.cm^{-2} according to the present calculations for proton showers (1) with the estimations of Sreekantan et al/9/ for proton (2) and iron (3) primary spectrum

Similar effect give the calculations of Danilova et al/13/. Assuming $k_{\pi-air} = 0.84$ they obtain less number of hadrons in extensive showers (with a factor of 2) than we have calculated with $k_{\pi-air} = 0.5$

More essential is the effect from energy increase of the inelastic cross section. The number of hadrons calculated in/9/ for $\sigma^{in}_{p-air} = 260 + 11\ \ln\left(\frac{E}{300}\right)^{1.4}$ is about 2 times smaller than in the case of logarithmic increase of σ^{in} assumed in our calculations.

The effect of primary particle mass on the properties of hadron component is illustrated in both figures 2 and 3 . We can see that even for the two extreme cases of pure proton and pure iron primary composition there is relatively small change in the energy spectrum of hadrons.

3. Comparison with experimental data In fig.1 we have compared the results for hadron lateral distribution obtained in our calculations with breaked scaling model and hadron densities compiled from different mountain experiments. It is seen that the slope of the theoretical curve differes from the experimental distribution. That difference is substantial near the core of showers, where the effect of multiple hadrons in hadronic detection is rather strong. Appart the apparatus effect, the observed disagreement can be due to the fact that in our model calculations we have neglected the possibility for appearence of secondary pions with large transverse momentum (above 1.4 Gev/c). In fact there is observed in accelerator experiments up to 2.10^5Gev slight decrease in the slope of p_t-distribution. Certainly, existence of such pions should cause a flatter lateral distribution of shower hadrons near the core. However, drastic change of p_t-distribution, needed to explain the contradiction in fig.1 was not observed over the entire range 0.2-10^3Tev. It might be supposed that the rise of transverse momenta at 10^3Tev could be attributed to only few secondary particles and jets/14,15/.

From the comparison with the experimental data in fig.2 we can see an apparent difference between the expected total number and the measurements with burst detectors. It is obvious that the model calculations are fitting the upper limit of hadronic flow detected with calorimeters.

4. Conclusion The above results allow us to conclude that we can get a better agreement with the average tendency of hadronic measurements if we assume in our new phenomenological model a larger coefficient of inelasticity and stronger energy increase of the total inelastic cross section in high energy pion interactions. Nevertheless, EAS data above 10^5Gev are revealing a faster development of hadronic cascades in the air than it can be expected by extrapolating the parameters of hadron interactions obtained in accelerator measurements.

References

1. Tonwar S.C. and Sreekantan V. J.Phys. A4,866,1971
2. Chatterjee B.K. et al. Canad. J. of Phys. 16,8,136,1968
3. Romachin V. et al. Proc. 15 th ICRC, 8, 107,1977
4. Nesterova N.M. and Chubenko A.P. Proc. 16 ICRC,8,346,1979
5. Nesterova N.M. and Dubovy A.C. Proc. 16 ICRC,8,845,1979
6. Van Staa R. et al. J.Phys. A1,135,1974
7. Miyake S. et al. Proc. 16 ICRC, 13,165,1979
8. Watcha R.H. and Sreekantan S.V. J.Phys. A6,1050,1057,1973
9. Sreekantan R.V. et al. Phys. Rew.(in press),1983
10. Popowa L. Acta Universitatis Lodziensis,1984,Lodz, Poland
11. Grieder P.K. Proc. 17 ICRC 6, 288,1981
12. Kempa J. Nuovo Cimento 31, 568,1979
13. Danilowa T.V. and Erlykin A.D. Preprint Number 15 of Lebedev Institute of Physics,Moscow,1984
14. Nikolski S.I. Journal of Theoretical and Experimental Physics 51,80,1966
15. Brasil-Japan Emulsion Chamber Collab.-AIP Conf.Proc.49,New Yourk 145,1979.