# THE METHOD FOR THE STUDY OF THE INELASTIC CROSS-SECTION FOR HIGH ENERGY PROTONS BY MEANS OF SHOWER ARRAYS WITH THE LARGE CALORIMETRIC AREA.

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Proton initiated showers could be reliably separated from showers initiated by cosmic ray nuclei by means of arrays with large calorimetric area, using distributions of energy fractions for EAS electromagnetic muon and hadron components. Proton initiated showers penetrate deeper into the atmosphere and have relatively lower energy fraction in muons. Distribution of that energy fraction is sensitive to the value of the proton inelastic cross-section. It is shown that the analysis of this distribution let one distinguish between $\log^2 S$ -rise and $\log S$ -rise of the cross-section at energies above $10^{15}$ eV.

Methods of the direct study of interactions stop working at energies above $10^{15}$ eV since intensities of primary particles and particles in the atmosphere are small at such energies. In connection with this future arrays for the study of interactions must be based on arbitrary methods, that is mainly on the study of EAS cores.

The absolute value and the energy dependence of hadron cross-sections determine the distribution of interaction points of hadrons in the atmosphere. This distribution determines the speed of the cascade development, if all other factors are identical. For the analysis of EAS detected at arrays with large calorimeter areas like ANI or AKENO it was proposed to use new classification parameters: the total energy of the shower $E_0$ or its energy at the observation level $E_Z$ /1/. Here $E_0 = E_{e\&\gamma} + E_h + E_{\mu\nu} + E_Q$ (1) for EAS where one succeeded to measure the Čerenkov light and by this way - the energy $E_Q$, lost by the shower in the atmosphere and $E_z = E_{e\&\gamma} + E_h + E_{\mu\nu}$ (2) for EAS without measurements of the Čerenkov light. Calorimeters with large areas let one measure rather accurately the energy carried by electromanetic $E_{e\&\gamma}$ and hadron $E_h$ components in every individual shower. The measure of the energy for the muon and neutrino component $E_{\mu\nu}$ is the total number of muons in the shower /1/.

In the paper / 1/ it was suggested to use the multidimensional analysis of tetrahedron and triangle diagrams - distributions of $E_{e\&\gamma}$, $E_h$, $E_{\mu\nu}$ and $E_Q$ for the study of

primary mass composition. Such an analysis helps to analyse the cross-section behaviour too, since
a)providing the good energy resolution it let better determine the energy of primary particles;
b)among primary particles with the given energy it let reliably separate proton induced showers;
c)the analysis of the shape of distributions $W(\delta_e, \delta_\mu, \delta_h)$ or $W(\Delta_e, \Delta_\mu, \Delta_h, \Delta_Q)$, where $\delta_i = E_i/E_z$, $\Delta_i = E_i/E_o$ in "proton" part of these diagrams is equivalent to the analysis of distributions for the speed of the cascade development of proton induced showers and finally, let one find the value of the cross-section at chosen energies.

Accuracy estimates for the energy determination of different EAS components at ANI array show that the shower energy at the observation level $E_z$ will be measured with $\sim 11\%$ accuracy. In the fig.1 the distribution of $E_o/\bar{E}_o$ ratio is shown for showers selected by $E_{700}$ classification parameter from 100 up to 316 TeV at the mountain level 700 $g/cm^2$ (full line) compared with similar distributions for showers selected by the total electron number $N_e$ in the interval $(1 - 1,58)\cdot 10^5$ (dotted line) and the muon number $N_\mu (>5$ GeV) in the interval $(1-1.58)\cdot 10^3$ (dashed line). All distributions are obtained by means of the simulation program /2/ for EAS with zenith angles $\theta \leqslant 30°$. Mass composition of primaries is similar to that at energies $\sim 10^{11}$ eV /2/. It is seen that the total shower energy $E_o$ may be determined by its energy at the observation level $E_{700}$ with inaccuracy ~19%. It is better, than in the case, when the primary energy is determined by $N_e$ or $N_\mu$, where the error is ~(37-38)%. In the combination with the error of $E_{700}$ determination this distribution gives on the average ~22% error in the determination of $E_o$ at ANI array when energies of three EAS components are measured. Measurements of the fourth component $E_Q$ let one reduce the error down to 8%.

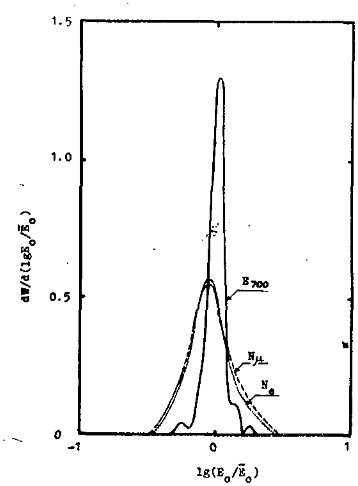


Fig. I.

The triangle diagram in the fig.2 demonstrates positions of gravity centres of $\delta_e$, $\delta_\mu$, $\delta_h$ distributions for primary particles of different masses, which induce showers with $E_{700}$ =31.6 - 100 TeV and 100-316 TeV. Here stars indicate positions of gravity centres for mixed primary composition. It is seen that all centres are located at one trajectory. Their position is determined by the energy

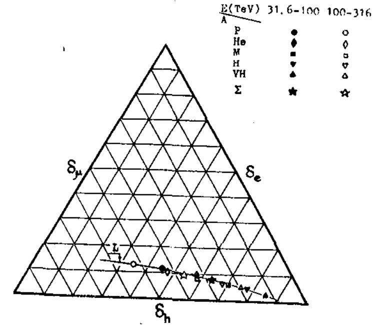


Fig. 2.

and the mass of the primary particle, i.e. depends in fact on the speed of the shower development. From this point of view the trajectory marked by the letter L may be called "the speed line".

Showers which develop faster are usually concentrated around points located at the right side of this line. In the left part on the average proton induced showers are concentrated which on the opposite, penetrate deeper into the atmosphere. The probability of such penetration and hence the $\delta_e, \delta_\mu, \delta_h$-distribution depends on the magnitude of the cross-section. The value of $\delta_\mu$ varies most quickly along "the speed line", therefore $\delta_\mu$ -distribution in the left part of the triangle diagram must be most sensitive to the proton cross-section $\sigma_{pA}^{prod}$. The ideology of this method is similar to that suggested by Ellsworth et al. /3/ for $\sigma_{pA}^{prod}$ determination by the distribution of shower maximum depth in the region of large depths, i.e. again by showers with slowest development.

The analysis of diagrams $W(\delta_e, \delta_\mu, \delta_h)$ for primary particles of different masses demonstrates that proton induced showers may be effectively selected from the mixture corresponding to the normal mixed composition, if to restrict the region by values $\underline{\delta_\mu} = \bar{\delta}_\mu -(0.1 \div 0.15)$. For example, for $E_{700}$ =100-316 TeV $\bar{\delta}_\mu$ =0,514. The probability for the proton induced shower to hit the region $\delta_\mu <$ 0,35 is 0,492, the same probability for helium induced shower is 0,155. For other primary nuclei it is 0. For the region $\delta_\mu <$ 0,4 these probabilities are $W_p$ =0,647; $W_{He}$ =0,246, $W_{M,H,VH}$ =0. Taking into account that protons in the ordinary mixed primary composition are about twice as abundant compared with helium nuclei, one can say that in the region $\delta_\mu <$ 0,35 86% of showers are proton induced and only 14% of them are helium induced. For $\delta_\mu <$ 0,4 these values correspond to 83% and 17%.

Shower distributions for different values of $\sigma_{pA}^{prod}$ and $\sigma_{\pi A}^{prod}$ differ most strongly just in the extreme left region of $\delta_\mu$. In the fig.3 distributions $W(\delta_e, \delta_\mu, \delta_h)$ are shown for proton induced showers with $E_o$ =(1-3.16) 10 eV and for two versions: with logarithmic ( $\sigma_{hA}^{prod} \sim \log S$ ) and maximum rising ( $\sigma_{hA}^{prod} \sim \log^2 S$ ) cross-section. The quantitative analysis of these bilateral diagrams made by means of Kolmogorov criterium shows that in the region $\delta_\mu <$ 0.4 these versions may be considered different with the probability to be wrong no more than 4%. At the same time the analysis of similar diagrams, calculated with constant or rising inelasticity does not reveal such a sensitivity.

In the fig.4 folded unilateral distributions $\Delta W / \Delta \delta_\mu$ are shown in the interval $\delta_\mu$ =0-04. Essential difference in the shape of these distributions confirms above mentioned expectations and let one hope for the practical realizability of this method.

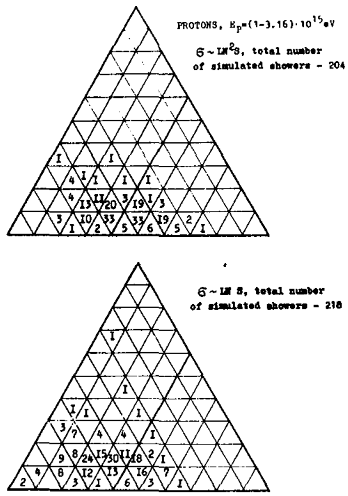


Fig.3

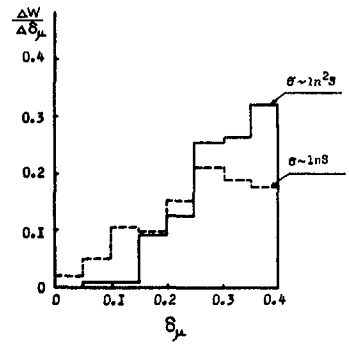


Fig.4

References.

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