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About the necessity of new small EAS experiments at observation levels 500–600 $\mathrm{g\,cm^{-2}}$

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Summary. — New small EAS experiments at observation levels 500–600 $\mathrm{g\,cm^{-2}}$ devoted to investigation of the primary mass composition and energy spectrum at energies 10^4–10^5 GeV are necessary to carry calibration between the direct (balloons and satellites) and indirect (EAS) methods for primary cosmic flux studies. A new shower selection has to be used in the attempt to obtain the possibility to apply compact EAS arrays for unbiased primary mass composition and energy spectrum estimations.

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1. – Introduction

Basic astrophysical problems connected with the investigation of the mass composition and energy spectra of the primary cosmic radiation are studied with the help of direct measurements carried out with balloon and satellite-borne apparatus [1-6], as well as on the basis of extensive air showers (EAS) experiments. Until now, it has been very difficult for direct experiments to exceed primary energies larger than 10^5 GeV and the EAS data are mainly correlated with energies no lower than 10^6 GeV. Moreover, the results of the corresponding indirect measurements, based on the EAS characteristics analyses, are usually carried out at observation levels larger than 700 $\mathrm{g\,cm^{-2}}$, where the absorption of the shower particles increases and the development "noise" becomes essential. At the same time, because of the quite different development of EAS initiated in the atmosphere by primaries with different masses A, the efficiencies $\varepsilon(A)$ [7-9] of EAS selected with fixed electron ($N_\mathrm{e} = \mathrm{const}$) or muon ($N_\mu = \mathrm{const}$) numbers, are considerably different [10, 11] for a given observation level.

It is clear that the optimal conditions for primary composition investigation could be realized when the selection efficiency $\varepsilon(A) \sim 1$. With this in mind, a new selection parameter $\alpha_\mathrm{e}(r_0)$ was proposed and defined in our previous works [7-9, 12] as $\alpha_\mathrm{e}(r_0) =$

$\eta(r_1, r_2, S_{\rm L})\rho_{\rm e}(r_0)$, where $\eta(r_1, r_2, S_{\rm L})$ is the value of a function basically reflecting the behaviour of the NKG function at relatively small distances r_1 and r_2 from the shower axis. $S_{\rm L} = S_{\rm L}(\rho_{\rm e}(r_1)/\rho_{\rm e}(r_2))$ is the local age parameter [13] estimated as a function of the ratio of the effective electron flux densities $\rho_{\rm e}(r)$ at distances r_1 and r_2. It becomes clear that the $\eta(r_1, r_2, S_{\rm L})$ function [7-9, 12] depends essentially on the observation level x_0 and the studied primary energy interval. The new selection parameter $\alpha_{\rm e}(r_0)$ based on shower parameters directly measured was experimentally checked [8] and it was shown that such an EAS selection could guarantee a value of the relative efficiency function $\varepsilon_{\rm e}(A) \sim 1$ for all initiating nuclei $A \in [1, 56]$. Then, this permits an unbiased estimation of the relative contributions W_A of the different main nuclei groups [14, 15] in the primary cosmic radiation.

Furthermore, by registrating small EAS with sizes $5 \cdot 10^3$–$5 \cdot 10^4$ at observation levels 550–600 $\rm g\,cm^{-2}$ [12, 16] and selecting them with the help of the new shower parameter $\alpha_{\rm e}(r_0)$, it could be possible to calibrate the indirect EAS methods for the primary mass composition and energy spectra estimations with the data obtained from direct experiments [1-6].

The aim of the present work is to analyse the possibilities to carry out small EAS experiments at observation levels $550 \le x_0 \le 600\ \rm g\,cm^{-2}$ taking into account the existing experimental facilities at Chacaltaya [17] and Tibet [18] cosmic ray laboratories estimating the primary mass composition on the basis of analysis of the muon-electron ratio fluctuations for the primary energies in the range 10^4–10^5 GeV. Furthermore, we claim that only the results obtained from such small EAS experiments could give the possibility for a practically unbiased calibration of the direct (satellites) and indirect EAS methods for the mass composition and energy spectra investigations of the primary cosmic flux.

2. – Method

The basis of the proposed method to calibrate direct and indirect methods for primary composition and energy spectra investigations is to study and analyse the muon flux fluctuations in small EAS, with energies 10^4–10^5 GeV, selected using the new shower parameter $\alpha_{\rm e}(r_0) = \rm const$. Then, the unbiased estimations of the relative contributions W_A of the five main nuclei groups: p, $\alpha[4]$, $M[14]$, $H[24]$, and $VH[56]$ can be obtained and compared with the corresponding data provided by direct satellite and balloon experiments [1-6].

The primary energy spectrum has to be obtained as the direct conversion of the EAS spectra $\mathrm{d}f(\alpha_{\rm e})/\mathrm{d}\alpha_{\rm e}$ obtained by selection of events with constant value of the new shower selection parameter $\alpha_{\rm e}$. The comparison of the EAS results with the corresponding data obtained from direct experiments could:

- avoid the possible systematical shifts of the indirect estimations obtained solving quite complicated inverse problems;

- help overcome some principal methodical difficulties, which will permit much more informative astrophysical analysis of the experimental results in the region of ultra high energies $E_0 > 10^5$ GeV.

The EAS selection parameter $\alpha_{\rm e}(r_0)$ [7-9, 12] is defined for the energy interval 10^4–10^5 GeV as

$$\alpha_{\rm e}(r_0) = \eta(r_1, r_2, S_{\rm L})\rho_{\rm e}(r_0)\,,$$

where the following parameters are chosen: $r_1 = 5\,\mathrm{m}$, $r_2 = 30\,\mathrm{m}$, $r_0 = 20\,\mathrm{m}$ for $x_0 = 550$ $\mathrm{g\,cm^{-2}}$ and $r_0 = 5\,\mathrm{m}$ for $x_0 = 606\ \mathrm{g\,cm^{-2}}$. In both cases, the local age parameter S_{L} [13] is defined as a function of the ratio of the electron flux densities at two distances close to the shower axis: $S_{\mathrm{L}} = S_{\mathrm{L}}(\rho_{\mathrm{e}}(5\,\mathrm{m})/\rho_{\mathrm{e}}(30\,\mathrm{m}))$. Because of the relatively low primary energies and hence the smallness of the electron flux densities, it was necessary to change a little bit the analytic formula for the determination of $\alpha_{\mathrm{e}}(r_0)$ given in [9] in an attempt to restrict the electron density measurements to a shorter distance range ($r < 30\,\mathrm{m}$).

The characteristics of the electron and muon components ($E_\mu \geq 0.6$ GeV) of EAS with energies 10^4–10^5 GeV for observation levels 550 $\mathrm{g\,cm^{-2}}$ and 606 $\mathrm{g\,cm^{-2}}$ were obtained using a three-dimensional Monte Carlo procedure based on a phenomenological interaction model SM1 [12, 19]. The model used for the nucleus-nucleus interactions is almost the same as that given by Boziev *et al.* [20, 21] which leads to the multiplicity fluctuations in the A-A collisions governed by the variations of the "wounded" nucleon number, which are essentially larger [11] than in the classical superposition model [15].

3. – Results

The main results are connected with the analysis and definition of the conditions necessary to obtain unbiased estimation of the primary mass composition at energies 10^4–10^5 GeV selecting small EAS and using the existing experimental facilities of the Chacaltaya and Tibet cosmic ray laboratories with particular changes of the detector locations and serious development of new low-energy muon detectors.

3·1. *Electron component of small EAS.* – Figure 1 shows that there are no essential differences between the calculated electron flux density for the observation levels 550 $\mathrm{g\,cm^{-2}}$ and 606 $\mathrm{g\,cm^{-2}}$. This gives the possibility to combine the analysis of the behaviour of the existing Chacaltaya [17] and Tibet [18] EAS arrays registrating small showers. Moreover, the calculated electron density fluxes $\rho_{\mathrm{e}}(r)$ for energies 10^4–10^5 GeV give the basis for analysis of the new selection parameter α_{e} proposed in our previous works [7-9, 12].

TABLE I. – *Primary energy estimation for* EAS *selection with* $\alpha_{\mathrm{e}}(5\mathrm{m}) = \mathrm{const}$ *at* $x_0 = 606\ \mathrm{g\,cm^{-2}}$. $\langle E_0\rangle$ *is the estimated average energy,* $\sigma(E_0)/\langle E_0\rangle$ *are the corresponding relative standard deviations taking into account only the fluctuations of the shower development,* $([\sigma(\alpha_{\mathrm{e}})/\langle\alpha_{\mathrm{e}}\rangle]_{\mathrm{rec}} = 0)$, *and the influence of the basic experimental conditions, detector response, data treatment, etc.,* $([\sigma(\alpha_{\mathrm{e}})/\langle\alpha_{\mathrm{e}}\rangle]_{\mathrm{rec}} = f(E))$, *where* $f(10^5\ \mathrm{GeV}) = 0.2$ *and* $f(10^6\ \mathrm{GeV}) = 0.1$.

$\alpha_{\mathrm{e}}(5\,\mathrm{m})$	$\langle E_0\rangle$ (GeV)		$\frac{\sigma(E_0)}{\langle E_0\rangle}$				$\frac{\langle E_0^{\mathrm{p}}\rangle - \langle E_0^{\mathrm{Fe}}\rangle}{\langle E_0^{\mathrm{p}}\rangle}$
			$\left(\frac{\sigma(\alpha_{\mathrm{e}})}{\langle\alpha_{\mathrm{e}}\rangle}\right)_{\mathrm{rec}} = 0$		$\left(\frac{\sigma(\alpha_{\mathrm{e}})}{\langle\alpha_{\mathrm{e}}\rangle}\right)_{\mathrm{rec}} = f(E)$		
	p	Fe	p	Fe	p	Fe	
$2 \cdot 10^2$	$0.912 \cdot 10^5$	$0.937 \cdot 10^5$	0.22	0.32	0.31	0.38	−1.8%
$5 \cdot 10^2$	$0.235 \cdot 10^6$	$0.241 \cdot 10^6$	0.19	0.22	0.25	0.27	−2.2%
$1 \cdot 10^3$	$0.480 \cdot 10^6$	$0.489 \cdot 10^6$	0.17	0.16	0.21	0.21	−1.6%
$2 \cdot 10^3$	$0.980 \cdot 10^6$	$0.989 \cdot 10^6$	0.15	0.12	0.19	0.16	−0.7%
$5 \cdot 10^3$	$0.251 \cdot 10^7$	$0.250 \cdot 10^7$	0.13	0.09	0.15	0.11	0.9%
$1 \cdot 10^4$	$0.513 \cdot 10^7$	$0.501 \cdot 10^7$	0.12	0.06	0.13	0.09	2.2%
$2 \cdot 10^4$	$0.105 \cdot 10^8$	$0.101 \cdot 10^7$	0.11	0.04	0.11	0.07	−3.6%

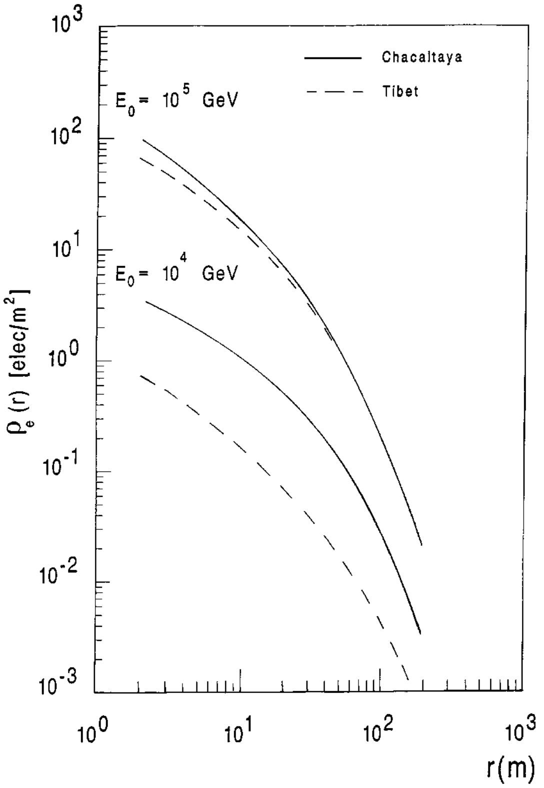

Fig. 1. – Electron flux lateral distributions at observation levels 550 g cm^{-2}(Chacaltaya: full line) and 606 g cm^{-2} (Tibet: dashed line) in EAS initiated by primary protons with energies 10^4 and 10^5 GeV.

3˙2. *The shower selection parameter* $\alpha_e(r_0)$ *and the primary energy estimation.* – The dependence of the primary energy on the selection parameter $\alpha_e(r_0)$ for the observation levels 550 g cm^{-2} and 606 g cm^{-2} and initiating primary protons and iron nuclei are shown in fig. 2. It is clearly seen that the shower selection with $\alpha_e(r_0) = \text{const}$ leads to collect events with the same primary energy E_0, independently of the atomic mass A of the initiating particles. However, the value of the selection parameter fluctuations $\sigma(\alpha_e)/\langle\alpha_e\rangle$, fig. 3, becomes reasonable only for energies $E_0 \geq 5 \cdot 10^4$ GeV for both the observation levels, which is only because of the development of the electron component in EAS with relatively low primary energies. Nevertheless, an acceptable primary energy estimation in the region $\sim 10^5$ GeV is possible even for the observation levels 550 and 606 g cm^{-2}.

The primary energy estimation $\langle E_0\rangle$ and the expected uncertainties $\sigma(E_0)/\langle E_0\rangle$ due to the shower development, $((\sigma(E_0)/\langle E_0\rangle)_{\text{rec}} = 0)$, and the experimental "noise", $((\sigma(E_0)/\langle E_0\rangle)_{\text{rec}} = f(E))$, for EAS selected with $\alpha_e = \text{const}$ at the observation level 606 g cm^{-2} are presented in table I.

The estimated accuracies are limited both by the shower development, $(\sigma(\alpha_e)/\langle\alpha_e\rangle)_{\text{dev}}$, and by the experimental "noise", $[\sigma(\alpha_e)/\langle\alpha_e\rangle]_{\text{rec}}$, which increases the value of the total fluctuation $[\sigma(\alpha_e)/\langle\alpha_e\rangle]_{\text{total}}$ according to $[\sigma(\alpha_e)/\langle\alpha_e\rangle]^2_{\text{total}} = [\sigma(\alpha_e)/\langle\alpha_e\rangle]^2_{\text{dev}} + [\sigma(\alpha_e)/\langle\alpha_e\rangle]^2_{\text{rec}}$. Taking into account the electron lateral distribution in EAS with energy 10^5 GeV at observation level 606 g cm^{-2}, it is easy to keep the

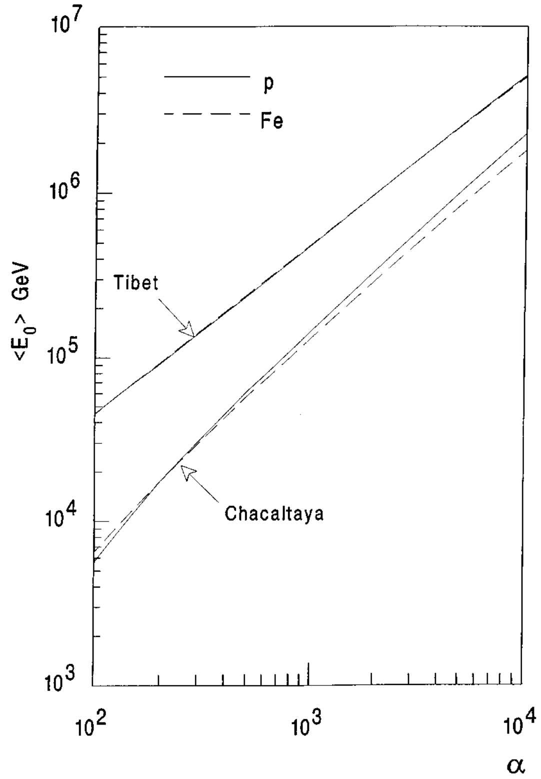

Fig. 2. – The dependence of the average primary energy $\langle E_0\rangle$ on the selection parameter $\alpha_\mathrm{e}(r_0)$ for showers generated by primary protons (full line) and iron nuclei (dashed line) at observation levels $550\,\mathrm{g\,cm^{-2}}$ and $606\,\mathrm{g\,cm^{-2}}$.

value of $[\sigma(\alpha_\mathrm{e})/\langle\alpha_\mathrm{e}\rangle]_\mathrm{rec}$ around 0.2 registrating the densities $\rho_\mathrm{e}(5\,\mathrm{m})$ and $\rho_\mathrm{e}(30\,\mathrm{m})$ with detectors with total effective area respectively no smaller than $4\,\mathrm{m}^2$ and $20\,\mathrm{m}^2$. Moreover, the changes of the $\rho_\mathrm{e}(5\,\mathrm{m})/\rho_\mathrm{e}(30\,\mathrm{m})$ ratio with $\pm 20\%$ lead only to small variations $\Delta S_\mathrm{L} = \pm 0.025$ of the local age parameter. The essential increase of the total detector effective area in the central part of the shower array [17, 18] would lead to an improvement of the axis localisation accuracy up to $\sigma(r) = 1$–$2\,\mathrm{m}$ by a corresponding optimal detector location. Therefore, adopting a realistic energy dependence $[\sigma(\alpha_\mathrm{e})/\langle\alpha_\mathrm{e}\rangle]_\mathrm{rec} = f(E_0)$, where $f(10^5\,\mathrm{GeV}) = 0.20$ and $f(10^6\,\mathrm{GeV}) = 0.10$, the average primary energy values $\langle E_0\rangle$ could be estimated with uncertainties $\sigma(E_0/\langle E_0\rangle) \in [0.2, 0.1]$ (table I) in the energy interval 10^5–10^6 GeV for EAS selected with $\alpha_\mathrm{e} = \mathrm{const}$ at observation level $606\,\mathrm{g\,cm^{-2}}$. The situation for the primary energy estimation selecting showers at the observation level $550\,\mathrm{g\,cm^{-2}}$ is similar, the only difference is the lower primary energy threshold: $5 \cdot 10^4$ GeV. Therefore, it becomes clear that, selecting EAS with constant value of α_e at Tibet and Chacaltaya observation levels, we could obtain the corresponding shower spectra $\mathrm{d}f(\alpha_\mathrm{e})/\mathrm{d}\alpha_\mathrm{e}$ [8] and, by this way, estimate the primary energy spectrum $\mathrm{d}f(E_0)/\mathrm{d}E_0$ [18] without any additional assumption about the mass composition of the primary cosmic radiation.

3˙3. *The muon component in small EAS.* – In an attempt to estimate the mass composition of the primary cosmic flux at relatively low energies 10^4–10^5 GeV, *i.e.* an

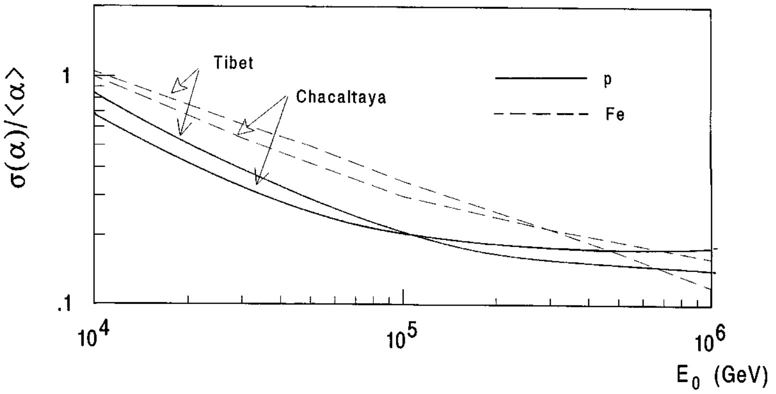

Fig. 3. – The fluctuations of the shower parameter α_{e} for different primary energies, for showers initiated by primary proton and iron nuclei at observation levels 550 $\mathrm{g\,cm^{-2}}$ and 606 $\mathrm{g\,cm^{-2}}$.

energy interval already covered by direct satellite and balloon experiments [1–6], the muon flux fluctuations in small EAS has to be studied. Taking into account the existing facilities [17, 18], the muon energy spectrum in EAS [10] and the construction costs of muon detectors for shower arrays, the muon energy registration threshold is chosen as $E_\mu \geq 0.6$ GeV.

The characteristics of the muon lateral distribution are calculated for primary energies 10^4–10^5 GeV (fig. 4). Taking into account the weakness of the muon flux in EAS for low primary energies and the difficulty to registrate muons with $E_\mu \geq 0.6$ GeV at small distances, we analysed the muon numbers inside the distance interval $15\,\mathrm{m} \leq r_\mu \leq 45\,\mathrm{m}$ from the shower axis (fig. 5). The conclusion for the behaviour of the low-energy muon component in EAS at observation levels 550–606 $\mathrm{g\,cm^{-2}}$ is the same as made for the electron component. This gives us the basis for a common study of the problems connected with the analysis of the fluctuation of the muon-electron ratio in order to obtain experimental information about the primary mass composition at energies around 10^5 GeV. As shown in our previous works [9, 12], the EAS selection according to the condition $\alpha_{\mathrm{e}} = \mathrm{const}$ leads to an essential decrease (by 30–40%) of the width of the muon fluctuations, $\sigma(N_\mu)/\langle N_\mu \rangle$, caused simply by the shower development in comparison with the usual selection when $N_{\mathrm{e}} = \mathrm{const}$.

3·4. *On the possibility of the primary mass composition estimation at energies* 10^4–10^5 GeV. – As shown in [9, 12], the collection of showers with $\alpha_{\mathrm{e}} = \mathrm{const}$ allows us to obtain direct information on the different components of the cosmic radiation *for the same energy* without being obliged to use the widely uncertain relation "size ⇔ energy". Taking into account the relatively small fluctuations of the muon component, it is possible to estimate the mass composition of the cosmic radiation for given primary energy $\sim 10^4$–10^5 GeV which involves no difference between the so-called "observed" and "primary" (real) compositions [10, 11] of the cosmic ray flux.

The most promising method [15,22,23] to obtain information for the primary mass composition remains the analysis of the shape of the muon fluctuation distributions $W(K_\mu)$, where $K_\mu = N_\mu/\langle N_\mu \rangle$, for $\alpha_{\mathrm{e}} = \mathrm{const}$ (*i.e.* $E_0 = \mathrm{const}$).

As in [12, 15, 23], the first approach is to check the sensitivity of the method using pseudoexperimental distributions $W(K_\mu)$ created by two alternative predictions for the

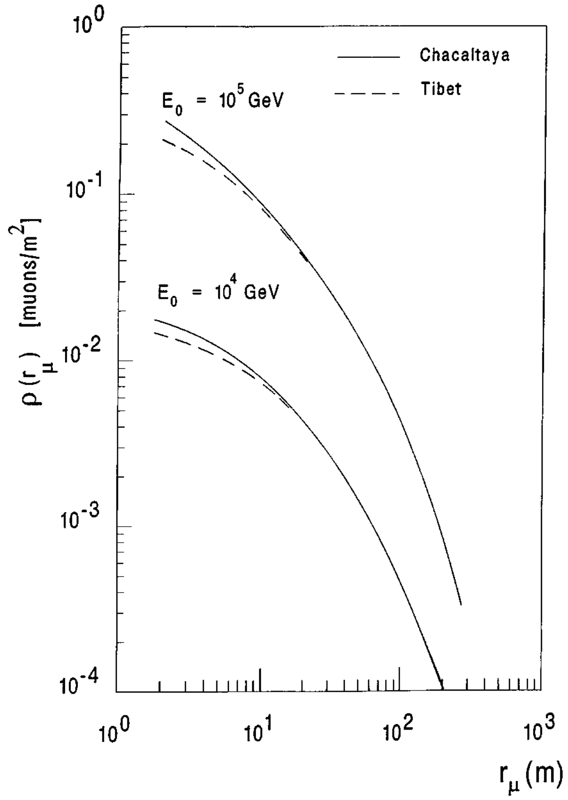

Fig. 4. – Muon flux ($E_\mu \geq 0.6$) GeV lateral distribution for proton-initiated EAS for energies 10^4 and 10^5 GeV at observation levels 550 g cm^{-2} and 606 g cm^{-2}.

primary composition: light [3] and heavy [24]. The inverse problem is solved supposing only the existence of the pure development "noise", $(\sigma(N_\mu/\langle N_\mu\rangle)_{\rm rec} = 0)$, and the "real" experimental situation characterized with the total value of noise $\sigma(N_\mu/\langle N_\mu\rangle)_{\rm rec} \simeq 0.35$. The results of the analysis are shown in table II.

4. – Chacaltaya and Tibet arrays and the possibilities for registration of small EAS

The recent detector arrangements of the Chacaltaya and Tibet arrays are described in [17, 18]. The Chacaltaya array consists of 28 × 1 m^2 scintillator counters uniformely displaced in the array 90 m × 90 m and 13 × 4 m^2 scintillation detectors arranged mainly

TABLE II. – *Check of the method which determines the mass composition of the primary cosmic radiation for a fixed value* $\alpha_{\rm e}(20\,{\rm m}) = {\rm const}$ *which corresponds to the fixed primary energy* 10^4 GeV *taking into account the reception conditions such as* $\sigma_{\rm rec} = 0.35$.

A composition	p	α [4]	M [14]	H [24]	VH [56]	$\langle \ln A\rangle$
light comp. [3]	36%	25%	14%	15%	10%	1.61
answer ($\sigma_{\rm rec}$=0.35)	(36±13)%	(25±12)%	(15±3)%	(14±3)%	(10±6)%	1.61
heavy comp. [24]	*16%*	*8%*	*10%*	*27%*	*39%*	*2.80*
answer ($\sigma_{\rm rec}$=0.35)	(17±2)%	(9±2)%	(7±2)%	(30±3)%	(37±3)%	2.79

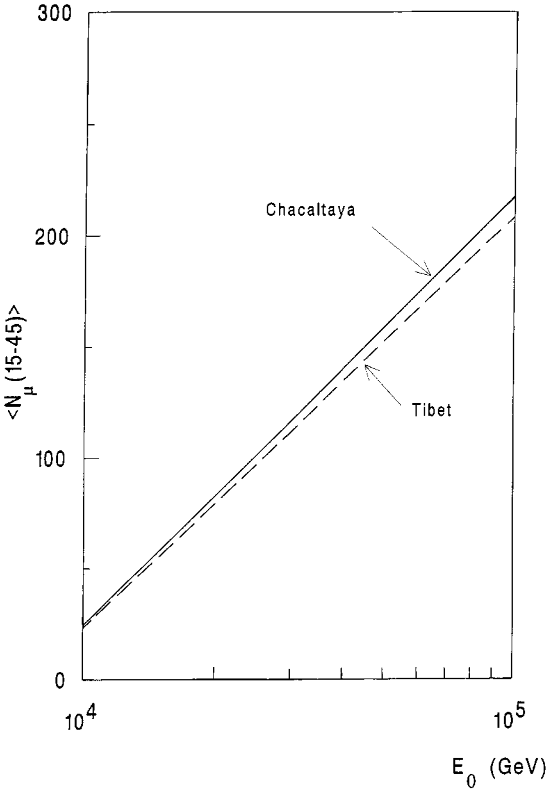

Fig. 5. – Dependence of the muon numbers estimated at a distance interval of 15–45 m from the shower axis on primary energy for observation levels 550 g cm^{-2} and 606 g cm^{-2}. Full line and dashed line are, respectively, for the Chacaltaya and the Tibet experiments.

in the central part, where the muon detector ($E_\mu \geq 0.6$ GeV) with a sensitive area of 60 m^2 is situated too.

The Tibet array consists of 185 fast timing scintillators with effective area 0.5 m^2 each. They are placed in a grid of a 15 m spacing and covering a total area of 270 m × 270 m. Muon detector does not exist.

Now, both arrays are not in the condition to registrate effectively small EAS with energies 10^4–10^5 GeV and to provide experimental data about the fluctuations of the muon-electron ratio in an attempt to carry out quantitative study of the primary mass composition.

In both cases, it is necessary:

i) to increase the number and effective area of the electron detectors in the central part of the array with dimensions 35 m × 35 m;

ii) to realize additional muon detectors with $E_\mu \geq 0.6$ GeV and effective area of 1500–1600 m^2, placed in the central part of the arrays;

iii) to create new triggering systems selecting showers with axis in a limited area around their central detectors in order to provide optimal condition for the use of the muon detector.

The rearrangement of the electron density detector location in the central part of the arrays is connected with the necessity to create new triggering systems and a denser de-

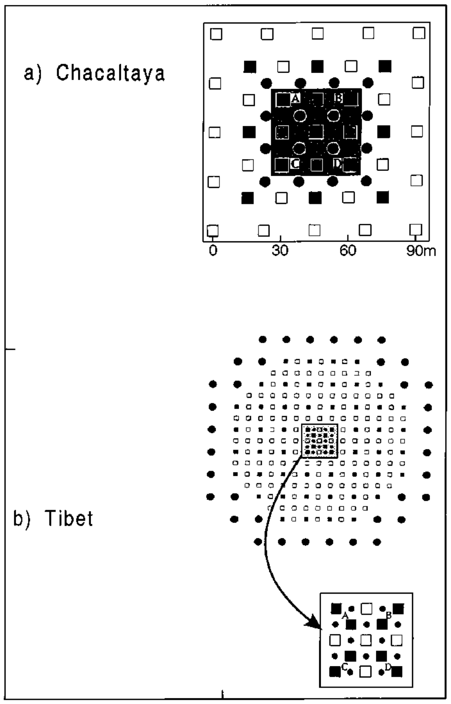

Fig. 6. – Detector location: a) Chacaltaya array [17]. Open and black squares: existing detectors, black circles: new detectors 1 m^2 each. Dark area: new muon detector with sensitive area 1600 m^2. A, B, C and D: new triggering systems. b) Tibet array [18]. Black circles and squares: existing situation. Shaded area: new muon detector with sensitive area 1600 m^2. Squares inside this area: developed existing detectors up to 4 m^4 each. Small black points: new scintillator counters, 1 m^2 each. A, B, C and D: new triggering systems as in a).

tector grid with a spacing not larger than 5 m, which guarantees a shower axis localisation with an accuracy $\sigma_\mathrm{R} \approx 1$–$2$ m.

A good starting basis for this is the central part of the recent [17] Chacaltaya array.

4·1. *The new triggering systems A, B, C, D.* – The new triggering systems A, B, C, D (fig. 6a)) are identical and could be realized with the help of the following three conditions:

$$m_\mathrm{C} \geq 5, \qquad \sum_{i=1}^{4} m_i \geq 50, \qquad \left(\frac{m_\mathrm{C}}{\sum_{i=1}^{4} m_i}\right) \geq 2,$$

where m_C is the number of particles in the central detector, m_i $(i = 1, 4)$ is the number of particles in the 4 peripheric detectors symmetrically placed around the central one. Similar triggering conditions were already used in the Tien Shan experiment [25] during the exploitation period 1966-1983. Using model calculations and experimental data [26], it was shown that such triggering logic leads to an effective registration of showers with energies higher than the given thresholds and with axes mainly inside a circle of radius $\sim$ 10 m around the central detector of each triggering system. Such triggering conditions have, as advantage, the registration of small EAS with a minimal total effective area of the electron flux detectors.

The central part of the Tibet array [18], fig. 6b), could be rearranged in a similar way, which will give also the possibility for an optimal use of a new created low-energy muon detector, specially in the study of small EAS.

For energies larger than 10^5–10^6 GeV, both EAS arrays could use the existing triggering systems.

4·2. *Design of the muon detector with* $E_\mu \geq 0.6$ GeV. – The calculated dependences of the muon flux densities at given distances from the shower axis *vs.* the energy of the primary protons show that the existing $60\,\mathrm{m}^2$ muon detector in the Chacaltaya array is not powerful enough for the registration of the muon flux in EAS with energies 10^4–10^5 GeV.

Indeed, we have seen that, to obtain a more or less definitive estimation of the primary mass composition analysing the muon flux fluctuations, the experimental "noise" must not exceed values ~ 0.35 [15, 23] and, further, that this noise limit is directly connected with the effective muon detector size.

At distances $r \leq 15\,\mathrm{m}$, the muon flux with $E_\mu \geq 0.6$ GeV is measured with difficulty because of the influence of the hadron flux close to the shower axis. Requiring the accuracy of the detector response to be less than 20% for events with energies $5 \cdot 10^4$ GeV, the effective area of the needed muon detector is estimated as $\sim 1600\,\mathrm{m}^2$.

Taking into account the proposed new triggering conditions for the registration of small EAS with energies 10^4–10^5 GeV, the preferable position of the $1600\,\mathrm{m}^2$ muon detector is at the center of the already operating array (figs. 6a) and b)). Clearly, only in this case a maximal effective area with distances $r_\mu > 20\,\mathrm{m}$ could be obtained. For bigger EAS, additional peripherical triggering systems would be needed [27] for a more effective utilisation of the new muon detector. It has to be pointed out that such a central detector gives optimal possibilities for selection of γ-initiated EAS at energies 10^5–10^6 GeV too [19, 28].

Consedering the need for a large effective area ($S_\mu \simeq 1600\,\mathrm{m}^2$), the most realistic solution are the Cherenkov watertank detectors placed under absorber (as used successfully in the GrapesIII experiment at Ooty [29]). In our case, the muon detector could be realized with the help of 256 units with $S_\mu = 5.8\,\mathrm{m}^2$ each viewed by one PM. The water depth would be 0.1–0.2 m, which would lead to a total weight of the needed distilled water of not smaller than 150 tons.

5. – Conclusion

New small EAS experiments at the observation levels 550–600 $\mathrm{g\,cm}^{-2}$ devoted to the investigation of the mass composition and energy spectrum of the primary cosmic radiation at energies 10^4–10^5 GeV are necessary in the attempt to obtain the calibration between the direct (balloons and satellites) and indirect (EAS) methods for the primary cosmic flux studies.

Taking into account the existing experimental facilities at the Chacaltaya and Tibet cosmic ray laboratories, it is shown that the application of the new shower selection parameter $\alpha_\mathrm{e}(r_0)$ guarantees a relative selection efficiency $\varepsilon_\mathrm{e}(A) \sim 1$, with an error of about 5%, for events initiated by primaries with different atomic numbers in the range $1 \leq A \leq 56$ and energies 10^4–10^5 GeV.

The rearrangement of the electron density detector location in the central part of the arrays is connected with the necessity to create new triggering systems and a denser detector grid with a spacing not larger than 5m inside the central part of the array with sides of $35\,\mathrm{m} \times 35\,\mathrm{m}$ minimum in order to guarantee a shower axis localisation with an accuracy of 1–2 m.

Four new EAS triggering systems have to be created, which registrate showers dominantly with axis inside a circle of radius $\sim 10\,\mathrm{m}$ around the corresponding central detector of the actual system.

In an attempt to obtain detailed information on the primary mass composition in the energy interval 10^4–10^5 GeV necessary for this calibration, a new muon detector with total effective area $\sim 1600\,\mathrm{m}^2$ has to be placed in the central part of the EAS array. The Cherenkov water detectors with an effective area of $5.8\,\mathrm{m}^2$ of each unit could provide a good basis. Moreover, for larger EAS, such a central powerful muon detector will give additional optimal possibilities for selection of γ-initiated EAS as muon-poor showers with energies 10^5 GeV.

All this provides the real possibility for the calibration of direct and indirect methods for primary cosmic flux study, which could avoid existing essential difficulties comparing the data in the field of astrophysics connected with the primary cosmic rays investigations at energies 10^6– 10^8 GeV.

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