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ABSTRACT

Two methods suitable to analyze very large amounts of data obtained by means of fast timing technique are presented together with preliminary results of a Monte-Carlo analysis of the effects of shower-front-thickness and instrumental instabilities.

АННОТАЦИЯ

Описаны два метода, пригодные для обработки больщого количества данных, полученных с помощью техники "fast-timing". Методом Монте-Карло проведен анализ для исследования влияний нестабильности аппаратуры и толщины фронта широких атмосферных ливней.

KIVONAT

Két módszert mutatunk be, amelyek alkalmasak "fast-timing" technikával kapott nagymennyiségü adattömeg feldolgozására. Monte-Carlo analizist végzünk a záporfront vastagság és a berendezés instabilitása hatásainak vizsgálatára.

INTRODUCTION

The fast-timing technique has been used to determine extreme high energy ($\gtrsim 10^{17}$ eV) angular distributions for a long time. As far as we know, the first attempt to apply it to lower ($\lesssim 10^{14}$ eV) energies has been made in the Tien Shan High Altitude Laboratory of the Soviet Academy of Sciènces by means of an apparatus designed and built in the Central Research Institute for Physics, Budapest, and operated by Bulgarian, Hungarian, and Soviet scientists. Description of the apparatus is given in [1].

The fast-timing technique as applied to $\lesssim 10^{14}$ eV particle fluxes raises several problems which do not emerge at high energies:

a/ The enormous amount of data /e.g. 10^7 events may easily be recorded during one or two years/ requires special methods of data analysis.

b/ The Poissonian fluctuations being very small, the quality of the results will largely depend on the extent to which meteorological effects and atmospheric absorption /zenith angle distribution/ can be corrected for.

c/ The same holds also for instrumental instabilities which require special treatment.

Various possible solutions of these problems are suggested and discussed in this paper.

It is assumed that the output of the fast timing device yields n_{ijk}, i.e. the number of extensive air showers /EAS/ with axes falling into the solid angle ω_{ij} during the interval Δt centered at $t_k = (k-\frac{1}{2})\Delta t$. The solid angles ω_{ij} are determined by parameters of the fast-timing device and corotate with the earth. Their position in interstellar space may be calculated, if t_k , the time of observation is given. In the Tien Shan experiment, values of ω_{ij} range from 3.5 to 5.5 millisterad, and Δt=5 minutes solar time.

DATA ANALYSIS: GENERAL CASE

Θ,α should denote polar angle and right ascension of a direction in the equatorial system, while ϑ,λ should be zenith angle and azimuth of a direction in the laboratory frame. If ω_{ij} is sufficiently small, the expectation of n_{ijk} may be written as

$$\langle n_{ijk}\rangle = I(\Theta_{ij},\alpha_{ijk}).M_k.A(\vartheta_{ij}).G(\vartheta_{ij},\lambda_{ij}).\omega_{ij}.\Delta t$$

where $I(\Theta,\alpha)$ is the angular distribution to be determined, M_k is the factor taking into account meteorological effects, $A(\vartheta)$ is the zenith angle distribution, and $G(\vartheta,\lambda)$ is the factor expressing the geometrical sensitivity of the experimental arrangement. In case of the Tien Shan experiment, $G(\vartheta,\lambda)$ has got the form [2]

$$G(\vartheta,\lambda)=\left[1-\frac{1}{4}\sin^2\vartheta-\frac{1}{16}\sin^4\vartheta+\frac{1}{32}\sin^4\vartheta\sin^2 2\lambda+\frac{1}{80}\sin\vartheta(|\cos\lambda|+|\sin\lambda|)\right]^{\gamma} \qquad /1/$$

with $-\gamma$ being the exponent of the integral density spectrum of EAS.

Although it is strongly advisable to determine all unknown parameters in one single process [3, 4] we shall, in this paper, suppose that the values of the meteorological coefficients and the constant of the zenith angle distribution are known. The method should then be generalized to include the evaluation of these parameters too.

Essential feature of the method to be described here is the subdivision of the celestial sphere of the equatorial system into a not too large number /say 30/ of solid angles $\Omega_p (p=1,2,\dots,r)$ in such a way that the number of showers to be expected in the various solid angles should be of the same order of magnitude. N_p should denote the total number of EAS observed in the solid angle Ω_p during the whole measurement lasting for the time T. Thus

$$N_p = \sum_{\omega_{ij} \in \Omega_p} \frac{n_{ijk}}{M_k} \qquad (p=1,2,\dots,r) \qquad /2/$$

and, of course,

$$\langle N_p \rangle = \iint_{o\Omega_p}^{T} I(\Theta,\alpha) A^*(\Theta,\alpha-t') G^*(\Theta,\alpha-t') \sin\Theta \, d\Theta \, d\alpha \, dt' \qquad /3/$$

where A^* and G^* are the same functions as A and G, respectively, only that the local (ϑ,λ) coordinates have been substituted by the equatorial ones, i.e. Θ and α, and t' is measured in sidereal hours.

The summation in Eq /2/ is not a straightforward one, rather has it to be taken into account that there may be ω_{ij} solid angles which overlap only partly with Ω_p and/or the overlapping may only take place during part of the period $(t_k - \Delta t/2,\ t_k + \Delta t/2)$.

Another essential point of the method is to note that

$$\int_o^T A^*(\Theta,\alpha-t') G^*(\Theta,\alpha-t') dt' = f(\Theta) \qquad /4/$$

is independent of α, provided that T, the total time of measurement is integral multiple of a sidereal day. The profile of the function $f(\Theta)$, for the case of the Tien Shan experiment ($\Theta_{TS}=47^o N$) may be seen in Fig. 1.

Let us develop $I(\Theta,\alpha)$ into a series of spherical functions which for our purposes should be labelled by one single index: $X_\mu(\Theta,\alpha)$ should be one of them; $X_o(\Theta,\alpha)$ should be $\equiv 1$; X_1, X_2, X_3 should be the first order functions, i.e. $\cos\Theta$, $\sin\Theta\cos\alpha$, and $\sin\Theta\sin\alpha$, respectively, and so on. Thus

$$I(\Theta,\alpha) = \sum_{\mu=o}^{m} B_\mu X_\mu(\Theta,\alpha) \qquad /5/$$

where $B_\mu(\mu=0,\ 1,\ 2,\ \ldots,\ m)$ are the parameters to be determined.

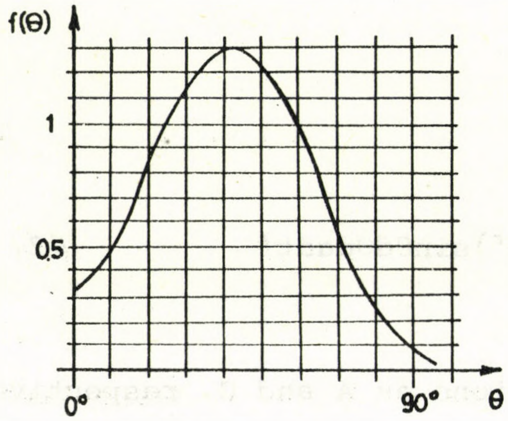

Fig. 1.

The function $f(\Theta)$ as defined en Eq /4/ and calculated for a one-sidereal-day observation with the Tien Shan apparatus ($\Theta_{TS}=47^oN$) with $A(\vartheta)=$ $=exp\left[6(1-1/cos\vartheta)\right]$ and $G(\vartheta,\lambda)$ as defined in Eq /1/.

Introducing /4/ and /5/ into Eq /3/ we have

$$\langle N_p\rangle = \sum_{\mu=o}^{m} B_\mu F_{\mu p} \qquad (p=1,2,\ldots,r) \qquad /6/$$

with $F_{\mu p}$ being numerical constants of known values:

$$F_{\mu p} = \int_{\Omega_p} X_\mu(\Theta,\alpha)f(\Theta)\sin\Theta d\Theta d\alpha \qquad \begin{matrix}(\mu=0,1,2,\ldots,m\\ p=1,2,\ldots,r)\end{matrix} \qquad /7/$$

It is reasonable to assume that the distribution of each measured N_p value is Gaussian with the mean $\langle N_p\rangle$ and variance proportional to $\langle N_p\rangle$, i.e. roughly to F_{op} , and that they are independent of each other. In this case the estimates of the values of B_μ and their variances can be determined by means of the method of least squares.

The largest amount of computer work is involved in the summation on the RHS of Eq /2/ and the calculation of the many $F_{\mu p}$ values /see Eq /7//.

THE METHOD OF THE "CROSSED TELESCOPES"

It is well known that the difference $I_2-I_1=I(\vartheta,\lambda_2)-I(\vartheta,\lambda_1)$ has got much larger signal to noise ratio than either of the observed intensities I_1 or I_2 , if "signal" means diurnal variation of $I(\vartheta,\lambda)$ and "noise" means meteorological effects. In $I(\vartheta,\lambda)$, the meteorological noise is usually dominant, whilst in I_2-I_1 the meteorological noise is usually negligible as compared to the Poissonian one.

This method can also be applied to the data obtained by the fast-timing technique. For this purpose, the ω_{ij} solid angles have to be arranged into pairs: ω_{ij} , $\omega_{\hat{i}\hat{j}}$, for which $\vartheta_{\hat{i}\hat{j}}=\vartheta_{ij}$ and

$$\left.\begin{aligned} &\lambda_{\hat{i}\hat{j}} = \lambda_{ij} + w\Pi/2 && (w=1 \text{ or } 2 \text{ or } 3) \\ \text{or}\quad & \\ &\lambda_{\hat{i}\hat{j}} = -\lambda_{ij} + w\Pi/2 && (w=0 \text{ or } 1 \text{ or } 2 \text{ or } 3) \end{aligned}\right\} \quad /8/$$

In this case we have

$$A(\vartheta_{\hat{i}\hat{j}})G(\vartheta_{\hat{i}\hat{j}},\lambda_{\hat{i}\hat{j}}) \equiv A(\vartheta_{ij})G(\vartheta_{ij},\lambda_{ij})$$

Let $n'_{ij\ell}$ be the number of EAS observed, within the solid angle ω_{ij} , during the interval $\Delta T'$, centered at $T'_\ell=(\ell-\frac{1}{2})\Delta T'$, where $\Delta T'$ is the interval of an equidistant subdivision of one sidereal day. $\Delta T'$ may e.g. be two sidereal hours. $n'_{ij\ell}$ can easily be calculated by adding up appropriate fractions of the appropriate n_{ijk} values observed in solar time.

Let us denote by $q(=1,2,\ldots,12)$ the serial number of a $\Delta T'=2$ hours long interval within a sidereal day. The sum of the $n'_{ij\ell}$ values belonging to $\Delta T'$ intervals with the same serial number q should be denoted by N'_{ijq} (q=1,2,...,12).

Let us subdivide the celestial sphere <u>of the laboratory system</u> corotating with the earth, into a not too large number, r, of pairs of solid angles ω_p and $\hat{\omega}_p$ (p=1,2,...,r); $\hat{\omega}_p$ should contain the $\omega_{\hat{i}\hat{j}}$ counterparts of the ω_{ij} solid angles contained in ω_p and vice versa. Let us calculate the values

$$D'_{pq} = \sum_{\omega_{ij} \in \omega_p} N'_{ijq} - \sum_{\omega_{\hat{i}\hat{j}} \in \hat{\omega}_p} N'_{\hat{i}\hat{j}q} \qquad \begin{matrix} (p=1,2,\ldots,r \\ q=1,2,\ldots,12) \end{matrix}$$

the meaning of which is obvious. It may be shown that

$$\langle D'_{pq} \rangle = B_1 C_{1pq} + B_2 C_{2pq} + \ldots + B_m C_{mpq}$$

with $B_1, B_2, \ldots B_m$ being the coefficients of the spherical harmonics of $I(\Theta,\alpha)$ and

$$C_{\mu pq} = S \int_{(q-1)\Delta T'}^{q\Delta T'} \int_{\omega_p} A(\vartheta)G(\vartheta,\lambda)\left[X^*_\mu(\vartheta,\lambda,t') - \right. \qquad /10/$$

$$\left. -X^*_\mu(\vartheta,\hat{\lambda},t')\right] \sin\vartheta d\vartheta d\lambda \cdot dt' \qquad (\mu=1,2,\ldots,m)$$

being numerical constants, where S is the number of sidereal days over which the observation is extended, $\hat{\lambda}$ is equal to $\pm\lambda + w\Pi/2$ /compare Eq /8//, and the functions X^*_μ are identical with the spherical functions X_μ, only that the equatorial coordinates (Θ,α) have been expressed by the local ones (ϑ,λ), and the sidereal time t' . The integrations in Eq /10/ may be carried out numerically.

Supposing that each D'_{pq} is distributed normally with the mean $\langle D'_{pq} \rangle$ as expressed in Eq /9/ and a variance proportional to $\int_{\omega_p} A(\vartheta)G(\vartheta,\lambda)d\omega$, the values of B_1 , B_2 , ..., B_m /note that <u>not</u> B_o/ and their variances can be estimated by means of the method of least squares.

THE EFFECTS OF SHOWER-FRONT-THICKNESS AND INSTRUMENTAL INSTABILITY

Both effects involve erroneous location of the ω_{ij} solid angles. So as to estimate the errors due to these effects, a Monte-Carlo analysis was performed in the following way:

Arrival of a total of $75\cdot 10^6$ EAS was simulated and $\tilde{n}'_{ijq}$, i.e. the total number of EAS arriving in the falsely located $\tilde{\omega}_{ij}$ solid angles in intervals of $\Delta T'=5$ sidereal minutes centered at $T'_q=(q-\frac{1}{2})\Delta T'$, $(q=1,2,3,\ldots,288)$ were determined by a Monte-Carlo process supposing that

a/ $I(\Theta,\alpha)$, the galactic angular distribution is known, i.e. concrete numerical values /"input values"/ of B_μ, $(\mu=1,2,\ldots,8)$, were chosen arbitrarily,

b/ $A(\vartheta)=\exp[6(1-1/\cos\vartheta)]$, $M_k\equiv 1$, and $G(\vartheta,\lambda)$ has the form given in Eq (1),

c/ apart from the distributions listed in paragraphs a/ and b/, the EAS arrive at random directions and times, i.e. with a distribution proportional to $d\omega dt$,

d/ the distribution of particles along a line perpendicular to the shower front leads to a Gaussian distribution of the arrival times of the particles at the detector surface with a variance of 8 nsec. No distinction was made in this respect between showers arriving at different zenith angles, even the $\cos\vartheta$ effect was neglected,

e/ the instrumental instability, as far as the determination of EAS directions is concerned, has the effect of distorting systematically the differences of the measured arrival times of EAS at the detecting surfaces. It was assumed that $\Delta\tau_1$ and $\Delta\tau_2$, the systematic errors of measured time differences were constant during a week, then suddenly changed by amounts obeying Gaussian distributions both with a variance of 0.8 nsec and expectation 0, remained constant again for a week, and so on. The total number of $75\cdot 10^6$ EAS was considered to have been observed during a sidereal year.

Having calculated the $\tilde{n}'_{ijq}$ data, the methods described in the preceding sections were applied to determine estimates of the parameters B which then were compared with the "input values" of them.

The analysis is not yet completed. Preliminary results show that shower-front-thickness and instrumental instabilities make impossible to determine values of B_1 and B_4 , i.e. the coefficients of $X_1=\cos\Theta$, and $X_4=(3\cos^2\Theta-1)/2$. Values and variances of all other coefficients can be estimated easily and reliably by means of the methods described in the previous sections. It is hoped that numerical results and a complete discussion of the Monte-Carlo analysis will be presented at the Conference.

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