The New Method of EAS Parameters Reconstruction Using the FWHM of Cherenkov Light Pulses.

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***Abstract*. Tunka-133 EAS Cherenkov light array constructing now in Tunka Valley (Siberia) will provide registration of pulse waveform with 5 ns step from every of 133 detectors. To use such unique abundant information the new method of EAS core position and depth of maximum (X_{max}) reconstruction, based on the measurement of Full Width at Half Maximum ($FWHM$) of Cherenkov light pulses has been developed. The method is based on the CORSIKA simulation and takes into account all the real apparatus characteristics.**

Using of a new width-distance function (WDF) will allow to reconstruct the EAS core position not only inside the array, but also at a certain distance beyond the array geometrical border. This can increase substantially the effective area for EAS registration in the energy range more than 10^{17} eV .

***Keywords*: Cherenkov pulse FWHM**

I. INTRODUCTION

The new EAS Cherenkov light array Tunka-133 will provide the data in the energy range 10^{15} – 10^{18} eV, in the range of core distances 0 – 1000 m and for a different arrival direction till the zenith angle 50° ([1], [2]). The pulse waveform from each detectors is measured by 200 MHz FADC boards [3]. Measuring of the EAS Cherenkov light pulse FWHM by each detector of the Tunka-133 array leads to the appearence of a new width-distance function (WDF) [4]. It is necessary to realize now how to use it in the analysis of the experimental data. This is the aim of the new simulation presented in this work. The previous simulations did not cover the whole energy range, distancies and zenith angles of the new array. The EAS Cherenkov light pulse width determined with a few additional detectors was used in previous experiments as a measure of the relative position of EAS maximum. Measurement of Cherenkov light pulse FWHM by all the detectors of the array provides the possibility to obtain the X_{max} more reliably and to develop the new method of EAS core reconstruction. The absence of FWHM random fluctuations and a simpler expression for the WDF with respect to the LDF one seems to allow us applying the new method of EAS core reconstruction not only inside, but also outside the array geometry, up to a certain distance.

II. FITTING OF CHERENKOV LIGHT PULSE

The primary data record for each Cherenkov light detector containes 1024 points of amplitude vs. time with the 5 ns time step. To derive three main parameters of the pulse: front delay at a level 0.25 of the maximum amplitude (t_i), pulse area (Q_i) and full width at half-maximum FWHM$_i$ the method of pulse fitting with the unique curve is used. The waveform of an EAS Cherenkov light pulse is complicated enought and cann't be fit with any simple function as Gaus or gamma functions. So we construct the function separetely approximating front and the droop of a pulse. Such approach was suggested in [5]. The expression from [5] has been improved to get the better fit at the beginning of a pulse front and at the beginning of a droop. The expression has 4 independent variables: A is a pulse amplitude, t_{max} is a time of a pulse maximum, t_{front} is a variable for a front description, t_{droop} is a variable for a droop description. The assisting variables are:

$$x = t - t_{max}$$
$$f = |x/t_{front}|$$
$$g = x/t_{droop}$$
$$h = \begin{cases} 1.7 - 0.5 \cdot g, & if \quad g < 0.8 \\ 1.3, & if \quad g \geq 0.8 \end{cases}$$

Using these variables the function for pulse waveform fitting is as follows:

$$f(t) = \begin{cases} A \cdot \exp(-f^{2+0.5 \cdot f}), & if \quad x \leq 0 \\ A \cdot \exp(-g^h), & if \quad x > 0 \end{cases} \quad (1)$$

This expression can fit the pulse waveform since the level of $0.1A$ at the front and till the level of $0.2A$ at the droop of the pulse. This is enough for the determination of a pulse parameters mentioned above. The example of usage of expression (1) is shown in fig. 1.

III. DISTORTION OF THE PULSE WAVEFORM.

The pulses are transmitted to FADC inputs via 100 m of coaxial cable RG-58 [2]. This cable together with pre-amplifier and PMT itself cause the extension of pulse till the minimal apparatus FWHM = 20 ns.

We examined the distortion of all the apparatus devices separately. The apparatus characteristics of PMT and pre-amplifier were obtained from observation of their reaction to the real short Cherenkov light pulse. CORSIKA simulation shows that the Cherenkov light pulse close to the EAS core is so short that can be treated as a δ-function. As a result of this analysis we came

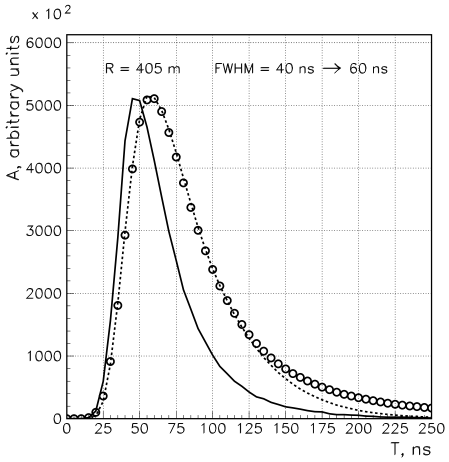

Fig. 1. Simulated appartus distortion of the Cherenkov light pulse. Full curve - the CORSIKA simulated pulse, circles - the convolution of the simulated pulse and the apparatus function, dotted curve - fit of the distorted pulse by the expression (1).

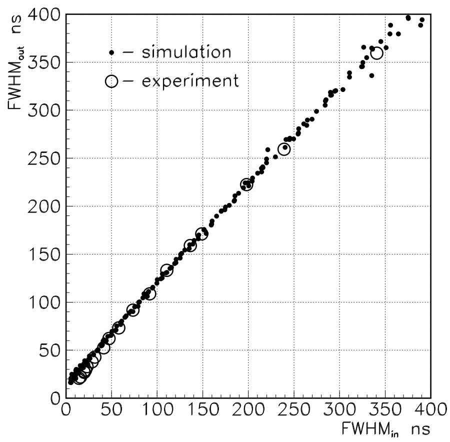

Fig. 2. Appartus distortion of the FWHM. Points - simulation, circles - experiment.

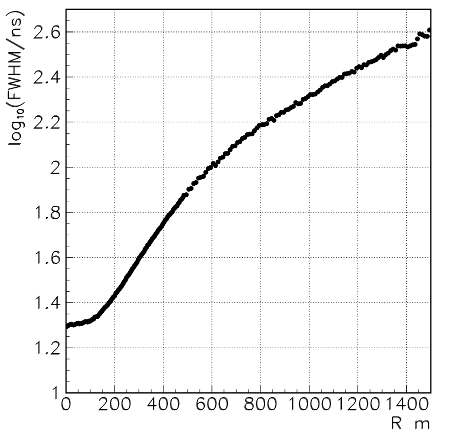

Fig. 3. Simulated width vs. distance function (WDF) for a single event.

to the conclusion that pulse characteristics of PMT and pre-amplifier can be treated like a Gaus functions with standard deviation about 5.7 ns.

To analyse the pulse characteristics of the cable we used triangle pulses from a pulse generator. Our analysis has shown that the cable distortion of the pulse is much more complicated than that of the local devices PMT or pre-amplifier. The pulse characteristics of the cable can be performed as the Gaus function with the standard deviation of about σ_t = 5.7 ns till the moment $(t_t - t_{max}) = 1.85 \cdot \sigma_t$, and after this time as a long tail of a $(t + t_0)^{-2}$ type ($t_0 = 25ns$).

Knowing the apparatus function one can obtain the pulse waveform at the output as a convolution of it with the input pulse waveform. Figure 1 presents an example of CORSIKA simulated pulse waveform together with a result of such calculation demonstrating the apparatus distortion of the pulse waveform.

Figure 2 presents the output FWHM of the channel as a function of input pulse FWHM. The simulation is compared with the experimental measurement described above. The small deviation of simulated points from the experimental ones for the FWHM $<$ 50 ns can be explained by the fact that experiment concerns to cable distortion only, but simulation has taken into account the influence of PMT and pre-amplifier too. The agreement of simulated and experimental points convinces us in the correctness of the used apparatus functions. One can see from the data in fig. 2 that a noticable distortion is observed till the FWHM of 400 ns.

To get the results suitable for the processing of the experimental data all the pulses obtained from the CORSIKA simulation has been affected by the convolution procedure described above.

IV. CORSIKA SIMULATION

To analyse the WDF and to derive the connection between the FWHM and the depth of EAS maximum X_{max} we used both the result of previous simulations for Tunka-25 experiment [6] and the new simulation provided especially for the Tunka-133. We use 120 events simulated for primary protons and Fe-nuclei with the energy 20 PeV and 3 zenith angles θ 0°, 15° and 25° from the previous work [6]. The output files of that simulation contained pulses waveforms with a step of 2 ns for distances from 2.5 m to 700 m with a step 5 m. The new set of simulated data containes 120 events from primary protons and Fe-nuclei with the energy 10 PeV and 30 events with the energy 30 PeV. The zenith angles are 0°, 30° and 45° in accordance with the sensitive apertura of the Tunka-133 optic detectors. The output files contain pulse waveforms with a time step 5 ns for the distances from 5 to 1500 m with a space step 10 m.

Figure 3 presents the simulated WDF for a single event. It is combined from two simulated events with

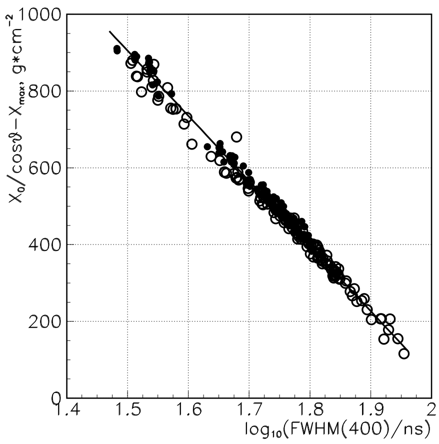

Fig. 4. Thickness of the air between the array and the EAS maximum vs. FWHM(400).

the same relative position of the EAS maximum, one of them with a time step 2 ns for distances < 500 m and another with a time step 5 ns for the larger distnce range. The shape of this curve confirms the shape of the experimental WDF presented in [4] but for distance < 500 m only. For the higher distance the slope of the curve becomes less. So to use WDF in a range of distancies wider than 500 m one needs more complicated analytic expression.

The WDF for all the other simulated events have the similar shape as presented in fig. 3 with varying value of FWHM(400) only. Figure 4 presents the connection between FWHM(400) and the thickness of atmosphere between tha detector and the EAS maximum $\Delta X_{max} = X_0/cos\theta - X_{max}$. Here $X_0 = 945g \cdot cm^{-2}$ is the vertical thickness of the atmosphere in the Tunka-133 site. This plot containes all the 270 points described above. One can see that the points for different zenith angles and different nucleus mass occupy the same curve with relatively small deflections.

V. Perspective of the new method using

To reconstruct the core position one can use the measured values of FWHM instead of photon flux and the simulated WDF instead of LDF. It is easily to notice that in such case we need only 3 varables to be reconstructed (2 core coordinates and FWHM(400)) as compared with the traditional method using which one has 4 variables (2 coordinates, LDF steepness and energy).

It seems that the absence of FWHM random fluctuations and a more simple expression for WDF instead of LDF will allow us applying the new method of EAS core reconstruction not only inside the geometrical area of the array, but also outside (up to a certain distance).

The accuracy of the new method of a core reconstruction both inside and outside the array border is currently under analysis. The results will be presented at the Conference.

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