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National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)

Wide fov cherenkov telescope

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Introduction

The geographical coordinates of the Yakutsk array are (61:70N;129:40E) and the site is 100 m above sea level. A schematic view of the present layout of the surface stations of the array and photos of a scintillation counter and the telescope are shown in Fig. 1. Forty-nine stations are distributed within a triangular grid of total area 8.2 km^2. The shower events are selected based on coincidence signals from n ≥ 3 stations, which in turn have been triggered by the two scintillation counters in each station. Complementary triggers at lower energies are produced by the central cluster consisting of 20 Cherenkov radiation detectors In a majority of previous measurements, analog signal readout systems were used that had narrow bandwidth, which restricted the possibility of pulse-shape reconstruction of the Cherenkov radiation from EAS; or, detectors were designed for measurement of the integral signal. In this paper, we describe a method for reconstructing the pulse shape of the Cherenkov radiation from EAS as detected using a WFOV Cherenkov telescope based on the coincidence of signals with the Yakutsk array.

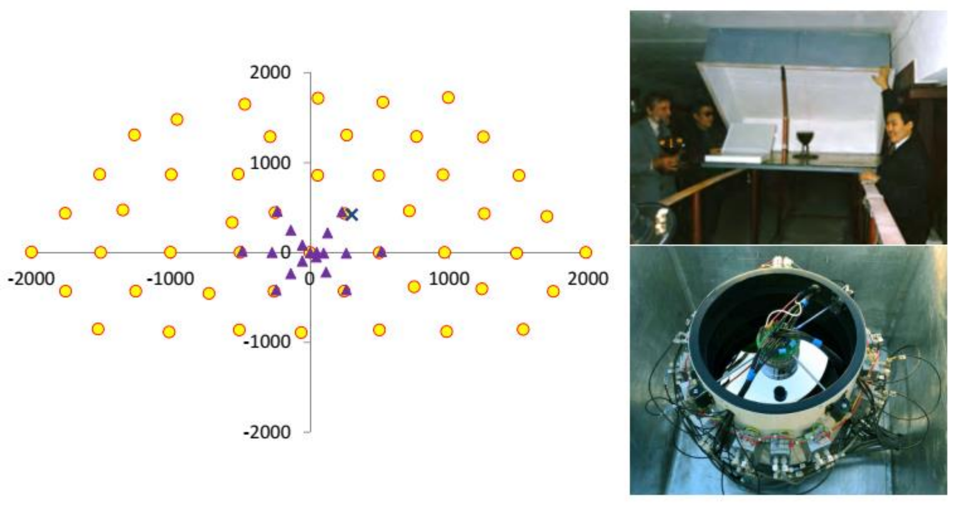

Figure 1. The map of surface stations of the Yakutsk array, distances in meters. Circles indicate stations with scintillation counters producing T500 trigger; triangles show the central cluster of Cherenkov radiation detectors producing an additional trigger. A cross marks the position of the telescope shown at bottom right. A scintillation counter is shown at the upper right

The data acquisition system

The data acquisition system (DAS) of the telescope consists of 32 operational amplifiers that have 300-MHz bandwidth AD8055 chips connected by long (12 m) coaxial cables to 8-bit LAn4USB ADC digitizers with 4-ns time slicing. All of the ADC output signals from the 32 channels are continuously stored in PC memory. A trigger signal from the EAS array terminates the process and signals in a 16/32 ms interval preceding a trigger are dumped. In Fig. 2, an example is given of the output signals of the DAS recorded in coincidence with the Yakutsk array detectors in a particular CR shower. The EAS parameters are estimated using the data from the surface array detectors. In Fig. 3, the two resulting responses from our two sources are shown. Indeed, the durations of the output signals in our system are much longer than those of input signals used. Consequently, both sources can be considered as suitable substitute for the input of a delta function.

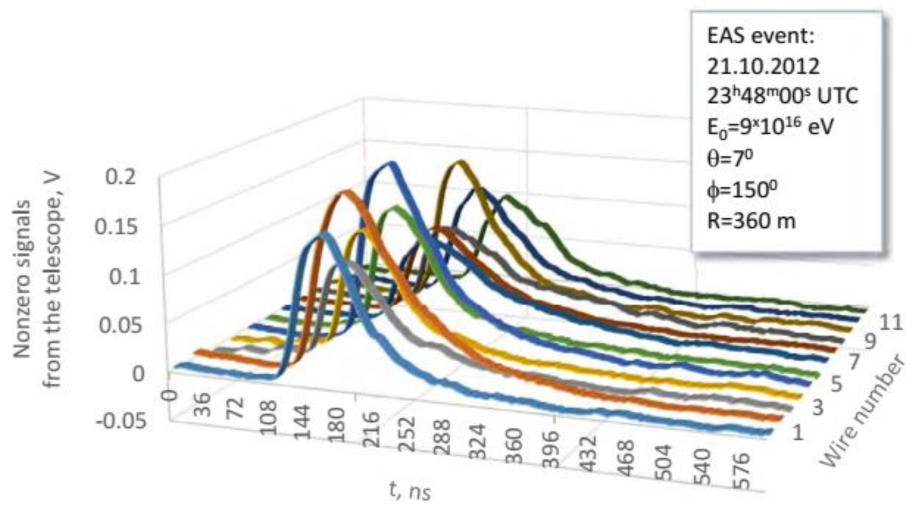

Figure 2. Output signals of WFOV Cherenkov telescope's data acquisition system from EAS event.

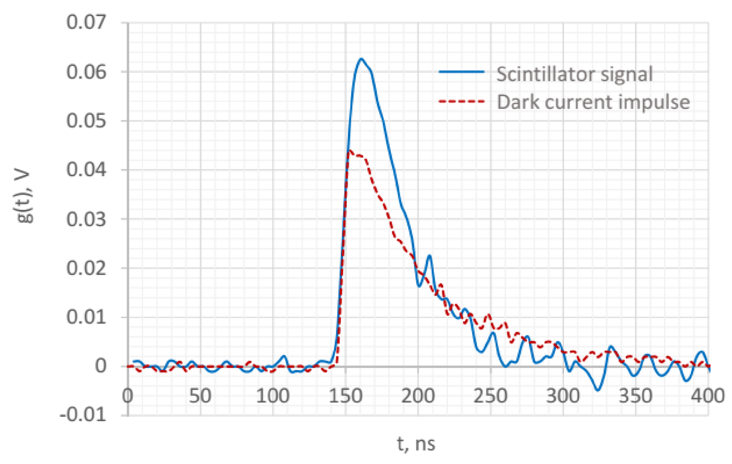

Figure 3. Impulse response of the system to short input signals.

IMPULSE RESPONSE OF THE DATA ACQUISITION SYSTEM

For the analysis presented here, we have used the impulse response to dark current impulses averaged over 18 measurements made 14 March 2018 (Fig. 4, left panel); this choice admits of no need for additional experimental equipment. In Fig. 4, an illustration is given of a real, noisy input signal naively deconvolved using the impulse response presented in the previous section. In order to carry out the Fourier (and inverse) transforms of digital signals, the fast Fourier transform (FFT) algorithm is used.

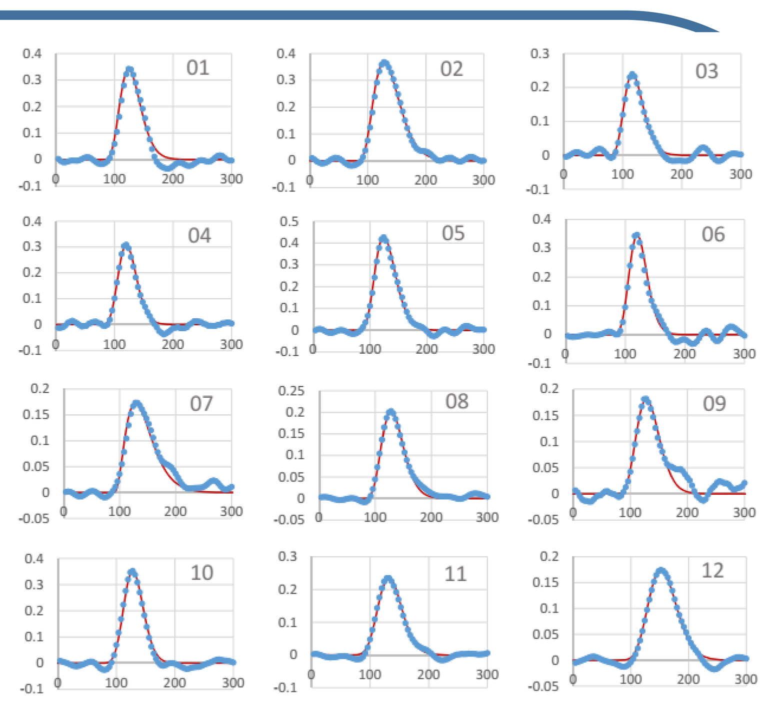

Figure 5. Gamma distribution approximation to Wiener deconvolution results in 12 channels. Horizontal axes: t, ns; vertical axes: fin(t) in arbitrary units. Reconstructed input signals are indicated by points; gamma distribution fits are shown by solid curves

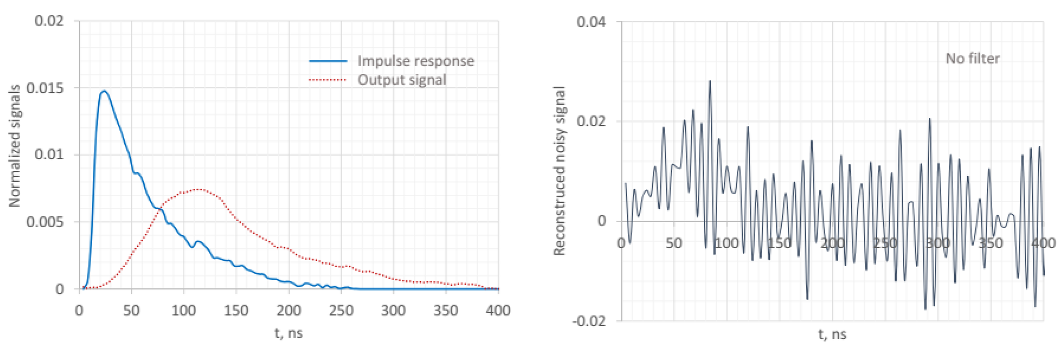

Figure 4. An example of reconstruction of the noisy signal. Left panel: Impulse response and the measured output signal of the system; Right panel: deconvolved input signal.

A TOY MODEL

The input signal is reconstructed using Wiener deconvolution as described in Section 3.2.1. The resulting signal is compared with the true input in Fig. 6 for different SNR. Increasing the noise fraction leads to a distortion of the reconstructed signal. The necessary condition on SNR in order to have an artifact in the Wiener deconvolution less than 1% is SNR> 56 dB. In Fig. 7, a ratio of FWHM of reconstructed and true input signals as a function of SNR is shown by the solid curve.

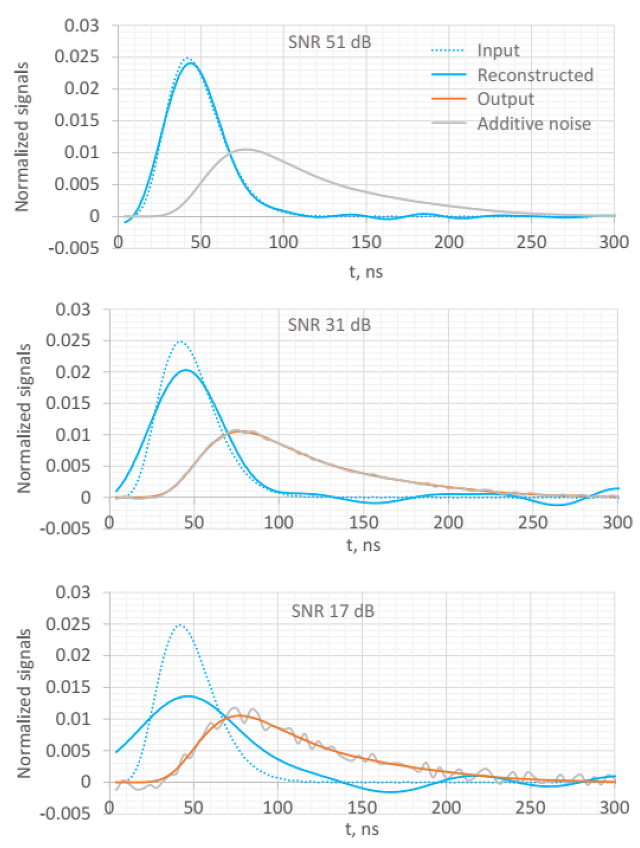

Figure 6. Wiener deconvolution of a noisy signal in a toy model.

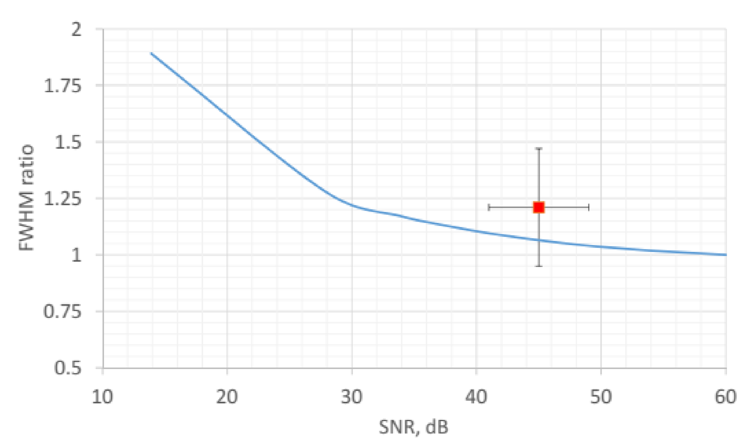

Figure 7. The ratio of durations of Wiener deconvolution and input signals vs SNR in a toy model (solid curve). The red square indicates the ratio of estimated signal durations of the telescope, as described in Section

LIGHT VERSION OF SIGNAL RECONSTRUCTION WITH INPUT GAMMA DISTRIBUTION

The resulting fitted output signals of the EAS event of 21.10.2012, 23h48m00s UTC are shown in Fig. 8 in comparison with experimental data. It appears that by having three adaptable parameters of the input gamma distribution, we may obtain a sufficient description of the observed output signal. However, as was shown with the toy model, the additive noise influence leads to a distortion of the deconvolved input signal, increasing with increased noise fraction, at least for the Wiener algorithm.

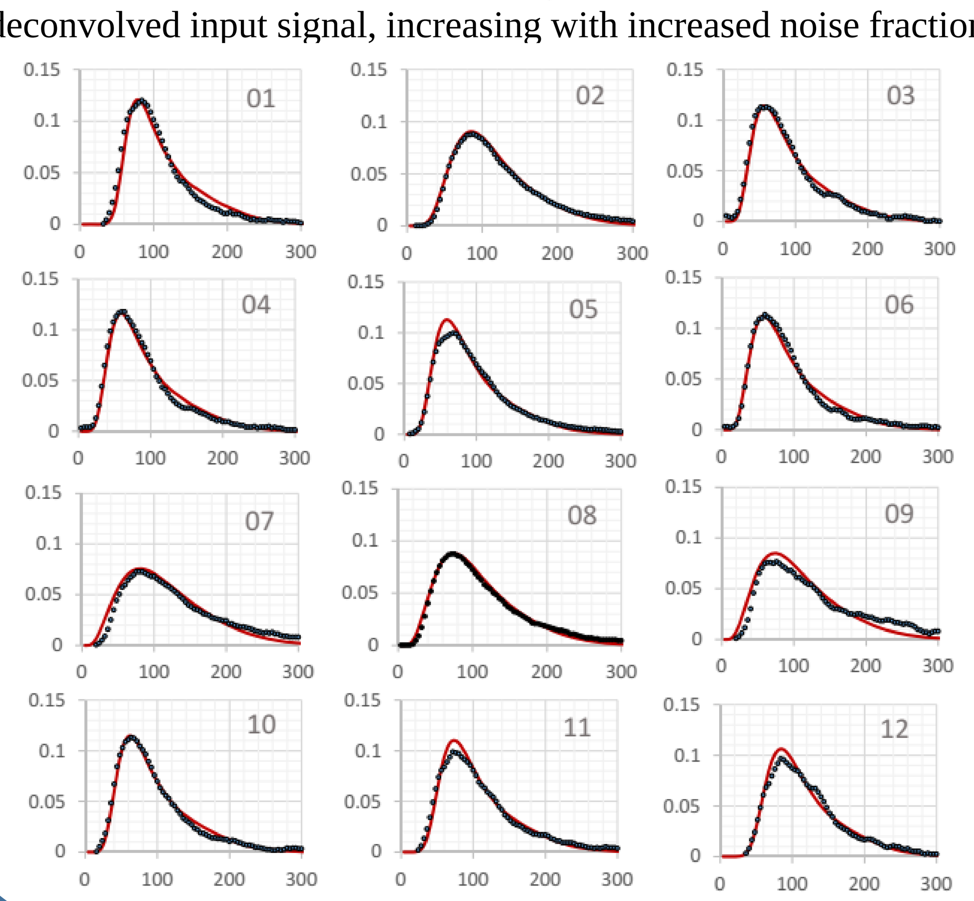

Figure 8. Measured and modeled output signals with fitted gamma distribution as input signals in 12 channels. Horizontal axes: t, ns; vertical axes: fout(t) in arbitrary units. Experimental data are indicated by points. The convolution of the impulse response and trial gamma distribution as an input signal is shown by solid curves in each channel

Conclusion

We have described the application of digital signal processing in order to reconstruct Cherenkov radiation signals, induced by EAS, from the data of a telescope working in co-operation with the surface scintillation counters of the Yakutsk array. The transfer function of the system is evaluated using a dark current impulse of the multianode PMT. Using this transfer function and a Wiener deconvolution algorithm, the input signal is reconstructed. The influence of noise parameterized with the signal-to-noise ratio is estimated using a toy model. It is found that the SNR of the WFOV Cherenkov telescope should be more than 56 dB in order to accurately reconstruct the input signal. It is demonstrated that the Cherenkov radiation signals from EAS can be approximated by a gamma distribution. Consequently, a simple method for reconstruction of such signals is proposed that does not require deconvolution. Moreover, the reconstruction method can be used to recover saturated signals.

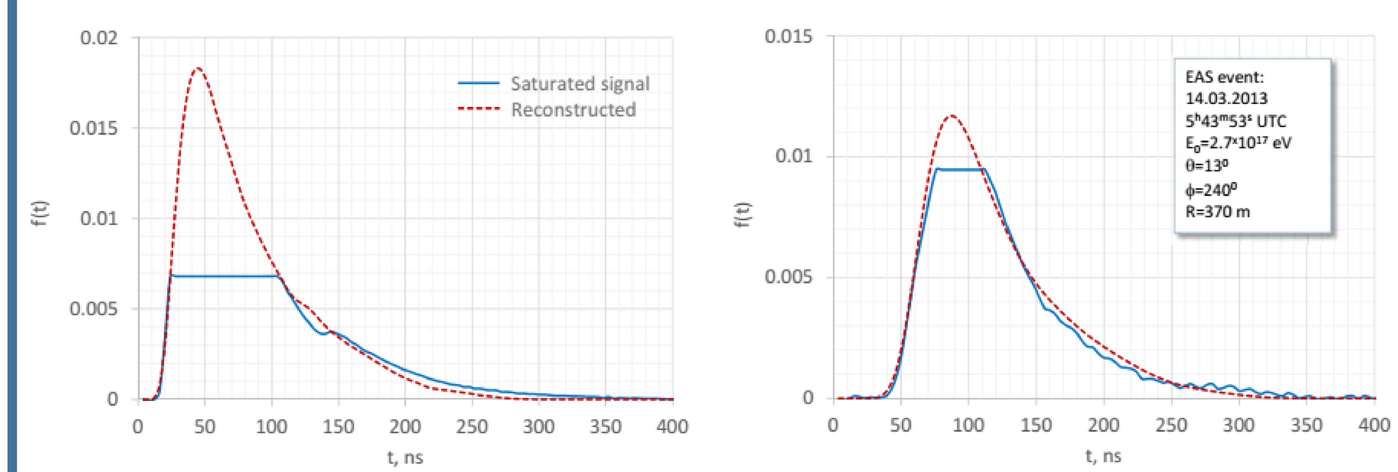

Figure 9. Reconstruction of two saturated output signals from EAS event denoted in the right panel

Acknowledges

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