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Abstract. HiSCORE is a non-imaging wide-angle Cherenkov array for the detection of extensive air showers induced by ultrahigh energy gamma-rays above 10 TeV and cosmic ray studies above 100 TeV. In October 2013 a 9-station engineering array has been deployed in Tunka valley. For HiSCORE-9, two DAQ systems are being used. The second system is a DRS4 based acquisition system with WhiteRabbit integrated time synchronization. We present the first results on the amplitude calibration from the data of this DAQ system.

1. Intoduction

HiSCORE is a new non-imaging wide-angle Cherenkov array for multi-TeV γ-ray astronomy and cosmic ray studies [1]. In October 2013 a 9-station engineering array with 150 m spacing has been deployed in Tunka valley at the site of the Tunka-133 array [2]. Currently a 34-station hybrid array in combination with an imaging telescope (TAIGA) is under construction [3].

Absolute detector calibration plays an important role in the definition of energy threshold and Monte-Carlo studies. In the past, many Cherenkov telescopes have been calibrated with the so-called excess noise factor method. The method applicable for HiSCORE optical detectors is discussed here.

2. Station and data acquisition

Each station is equipped with four 8″-PMTs. Currently ten-stage Hamamatsu R5912 PMTs are being used [4]. Each PMT has a Winston cone with 0.4 m diameter and 30° viewing angle to concentrate light onto the PMT. The station has a collection area of 0.5 m^2 and a field of view of about 0.6 sr. The signals from the 7th ("anode") and 5th ("dynode") dynodes are used. The last three dynodes and anode are shorted. Such a scheme provides a gain of $2 \cdot 10^4$ at the voltage of $1000 - 1100$ V to keep the night sky current at the accepted by the PMT level of 100 μA. In addition the signals are amplified with a factor 20 (anode) and 4 (dynode).

For HiSCORE-9, two DAQ systems are being used (see Figure 1). The first is a DRS4 based 8-channel optical station board with a custom synchronization board placed in the DAQ center [5]. The second one is a DRS4 based acquisition system with WhiteRabbit integrated time synchronization [6]. The systems serve for data quality cross checks and all necessary tests in order to achieve sub-ns synchronization and best performance. The data from the second DAQ system are used in this paper.

Anode and dynode signals from every PMT are connected to the summator. Anode signals are summed up. The sum is used for the trigger. The trigger is built with the FPGA on-board the WhiteRabbit card.

We store three anode signals to one DRS4 evaluation board and a fourth anode signal, dynode signal and sum to another DRS4 board. Additionally, every board samples the WhiteRabbit trigger signal for calibration of the time-frame of the DRS4.

Data are transferred from the RaspberryPi PC directly to the central DAQ PC via ssh connection.
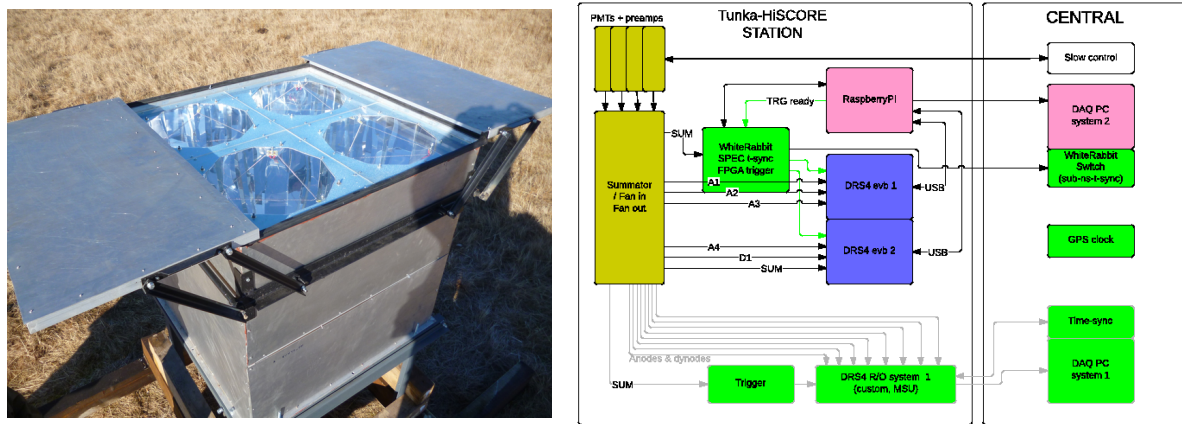
Figure 1. View of the optical station and DAQ set-up scheme.

3. Amplitude calibration

3.1. Excess noise factor method

For calibration, a fast and powerful distant LED source was used in February-March 2014 (5 runs: 22.02, 25.02, 07.03). The horizontal light source illuminated 45° reflectors at each station. Here, the amplitude calibration is discussed. Results on the time calibration are shown in [6].

By knowing the amplitude of the LED signal stored in the DRS one can extract the number of photoelectrons. Assuming that the number of photons falling on the photocathode has a Poisson variance and noise variance is negligible one can derive the conversion factor:

$$C = F \frac{\mu}{\sigma^2} \text{ [p.e./mV]}, \tag{1}$$

where F is the excess noise factor, σ is measured variance and μ is the mean of the LED amplitude distribution (see Figure 2).
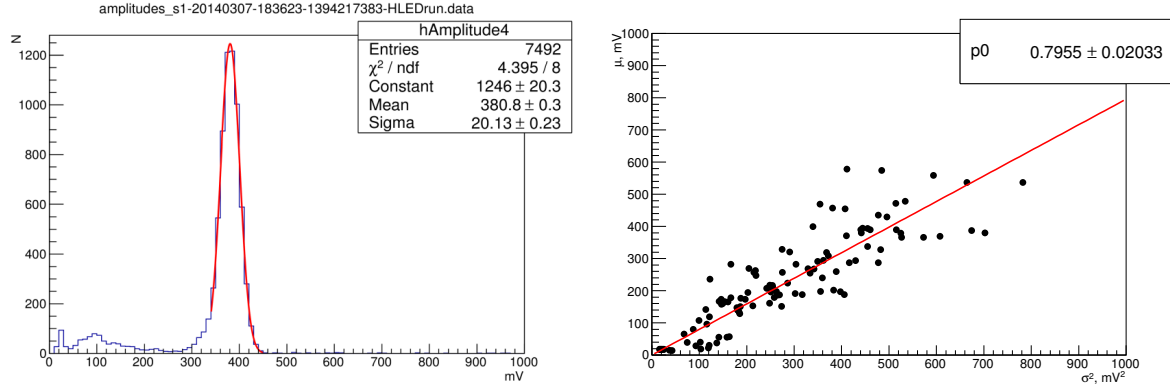
Figure 2. An example of a LED amplitude distribution and its Gaussian fit (*left*). Summary scatter plot of σ^2 and μ of anode channels for all runs ($\chi2/ndf < 10$) (*right*).

3.2. Determination of F

The mean μ_1 and standard deviation σ_1 of the single photoelectron spectrum (with subtracted pedestal) is related to the excess noise factor of the PMT by the following definition [8]:

$$F = 1 + \frac{\sigma_1^2}{\mu_1^2} \tag{2}$$

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However the single photoelectron spectrum is very difficult to measure by using our PMT due to its low gain. An alternative would be to use the gain to calculate the excess noise factor. The gain of each PMT is regularly measured in the laboratory before the PMT is deployed.

The excess noise factor is related to the collection efficiency of the photomultiplier CE and the secondary emission ratio δ [7]:

$$F = \frac{1}{CE}\left(1 + \frac{1}{\delta_1} + \frac{1}{\delta_1\delta_2} + ... + \frac{1}{\delta_1\delta_2...\delta_n}\right), \tag{3}$$

where δ_i is the secondary emission ratio of i-th dynode and n is total number of dynodes.

With $\delta_1, \delta_2, ..., \delta_n = \delta$, equation (3) for large n is simplified as follows:

$$F \simeq \frac{1}{CE}\frac{\delta}{\delta - 1}. \tag{4}$$

The average secondary emission ratio δ is a function of the interstage voltage of dynodes and can be derived from the gain:

$$\delta = \left(\frac{G}{CE}\right)^{1/n} = 5.4\left(\frac{G}{2\cdot 10^4}\right)^{1/6}\left(\frac{CE}{0.8}\right)^{-1/6} \tag{5}$$

And finally one obtains the noise excess factor:

$$F = 1.5\left(\frac{CE}{0.8}\right)^{-1}. \tag{6}$$

Thus for $F=1.5$ the average conversion factor C is 1.2 p.e./mV.

Results on application of the calibration to data taken on 25 February 2013 are shown in Figure 3. For one chosen station, calibrated differential spectra reach their maxima at $\log_{10} A/$p.e.: 1.85, 1.79, 1.70, 1.77. Thereby the estimated discriminator threshold of the station with four PMTs:

$$A_{thr} = 10^{1.85} + 10^{1.79} + 10^{1.70} + 10^{1.77} = 241 \pm 16 \text{ p.e.} \tag{7}$$
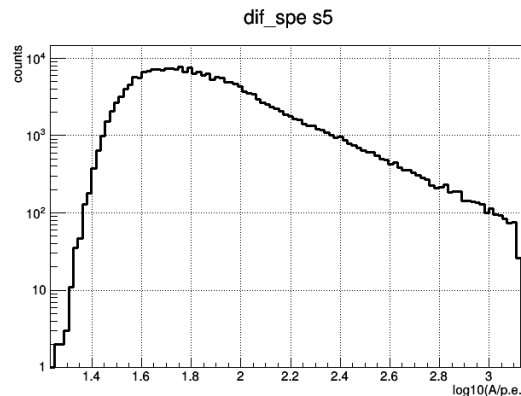
Figure 3. Calibration to photoelectrons for station five. Channel number three is shown.

4. Conclusion and outlook

The excess noise factor method was used for calibrating of many Cherenkov telescopes in the past. However classical determination of the noise factor F using single photoelectron spectrum is difficult in case of our type of PMT. An alternative way of definition of F is to use the gain of the PMT and can be used in the experiment. A dedicated calibration system will be installed in the future.

5. Acknowledgements

References

[1] M. Tluczykont et al. Towards Gamma-Ray Astronomy with timing array, this conf.

[2] N. Budnev et al. The Tunka experiment: from cosmic ray to gamma astronomy, this conf.

[3] M. Kunnas et al. Simulation of the Tunka Area International Gamma-ray Advanced experiment (TAIGA), this conf.

[4] Hamamatsu Photonics K.K. Photomultiplier tube R5912. Retrieved from `http://neutron.physics.ucsb.edu/docs/R5912_8inch.pdf`

[5] N. Budnev et al. A prototype DAQ for the Tunka-HiSCORE: 8-channel DRS-4 board, this conf.

[6] A. Porelli et al. Timing calibration and directional reconstruction for Tunka-HiSCORE, this conf.

[7] Hamamatsu Photonics K.K. Photomultiplier tubes. Basics and applications. 2006. Retrieved from `http://psec.uchicago.edu/links/pmt_handbook_complete.pdf`

[8] Th. Schweizer et al. The Optical Calibration of the MAGIC Telescope Camera. IEEE Transactions on Nuclear Science. San Diego. 2001.