PROCEEDINGS OF SCIENCE

New concept of timing calibration systems for large-scale Cherenkov arrays in astroparticle physics experiments.

Bayarto Lubsandorzhiev[1]
Institute for Nuclear Research of the Russian Academy of Sciences
Pr-t 60-letiya Oktyabrya 7a, Moscow, Russia
E-mail: lubsand@rambler.ru

Svetlana Krokhaleva
Institute for Nuclear Research of the Russian Academy of Sciences
Pr-t 60-letiya Oktyabrya 7a, Moscow, Russia
E-mail: sultim@inbox.ru

Nima Lubsandorzhiev
Institute for Nuclear Research of the Russian Academy of Sciences
Pr-t 60-letiya Oktyabrya 7a, Moscow, Russia
E-mail: nilubs@rambler.ru

Sultim Lubsandorzhiev
Institute for Nuclear Research of the Russian Academy of Sciences
Pr-t 60-letiya Oktyabrya 7a, Moscow, Russia
E-mail: sultim@inbox.ru

Bator Shaibonov
Institute for Nuclear Research of the Russian Academy of Sciences
Pr-t 60-letiya Oktyabrya 7a, Moscow, Russia
E-mail: b.shaibonov@gmail.com

Roman Poleschuk
Institute for Nuclear Research of the Russian Academy of Sciences
Pr-t 60-letiya Oktyabrya 7a, Moscow, Russia
E-mail: roman.poleschuk@gmail.com

We present new approaches in timing calibration systems for large-scale Cherenkov arrays in astroparticle physics experiments like Cherenkov arrays detecting extensive air showers (EAS) and water Cherenkov neutrino arrays. The concepts are based on multiple distributed fast LED light sources driven by a single trigger pulse unit or a single fast powerful LED source fixed above arrays even on a board of a pilotless remotely controlled helicopter.

The 34th International Cosmic Ray Conference
30 July- 6 August, 2015
The Hague, The Netherlands

[1]Speaker

PoS(ICRC2015)1036

1. Introduction

Timing calibration in astroparticle physics experiments with sparsely distributed photon detectors like in Extensive Air Showers (EAS) Cherenkov arrays and underwater high energy neutrino telescopes is not simple experimental task. Indeed spacing between photon detectors in EAS Cherenkov arrays operating in the energy range of cosmic rays 10^{15}-10^{17} eV is in the order of 100 m or more, for higher energies the spacing is much more exceeding 1 km. How to carry out timing calibration of individual photon detectors of such arrays, i.e. how to define simultaneousness of photon detectors firing or in other words how to define T_0 for all photon detectors of the array. The problem is far from trivial. In case of underwater Cherenkov arrays the situation is not much easier. The distance between their optical modules is in order of 10 m and more and distance between strings is of several dozen. In both cases to use single very powerful light source like powerful fast laser is problematic and expensive, especially in case of EAS Cherenkov arrays. The advent of ultra bright and high power fast blue/UV light emission diodes (LEDs) opened new possibilities for designing timing calibration systems for such kind of experiments.

2. Timing calibration systems based on LEDs.

To overcome all problems mentioned above we proposed several approaches.

1. For underwater arrays ultra bright fast blue LEDs allow to build a simple system where each string of arrays will be equipped with light sources which are triggered by pulses from a single electronic module. Trigger pulses are fed to light sources via long coax cables.

2. In case of EAS Cherenkov array each photon detector of the array will be equipped by a fast LED source which triggered too from a single electronic module via coax cables.

3. All photon detectors of EAS Cherenkov array are illuminated by short light pulses from a single powerful light source fixed at long pole/tower or balloon or on board of pilotless helicopter well above the array.

4. In both cases it is possible to use fast LED sources for each photon detectors of arrays and trigger them using high quality clock system with very good synchronization between clocks.

3. Timing calibration systems for underwater neutrino telescopes

Lets start with timing calibration systems of underwater experiments. Ultra bright blue LEDs suit very well for such application. They are fast enough, it is possible to design light sourse with 1 ns width light pulses and high intesity. Their emission spectra match well with water transparency at experiments sites. We developed a system [1, 2] escpecailly for Lake Baikal neutrino experiment NT-200+ [3] which was an extension of the first undewater neutrino telescope in the world – NT-200 [4]. For this extension three additional distant strings were fixed around existing NT-200 telescope. The calibration system consisted of four deep underwater nanosecond light sources fixed at each outer string of NT-200+ and one of peripheral strings of NT-200 above optical modules of strings (blue circles in fig.1). All light sources are triggered simultaneously from one electronic unit arranged in deep underwater module and fixed at one outer string at distance of ~1 km. In fig.1 this module is depicted by red circle. Each light source module is connected with triggering module by 1.2 km long coaxial cable. The time jitter of triggering pulses after passing of 1.2 km long coaxial cables are less than 75 ps, see fig.2. The upper part of the fig.2 shows the jitter measuring principle. All optical modules of outer strings are illuminated by light sources via plastic optical fibers of equal length. As for a peripheral string of NT-200 its optical modules are illuminated directly through water.

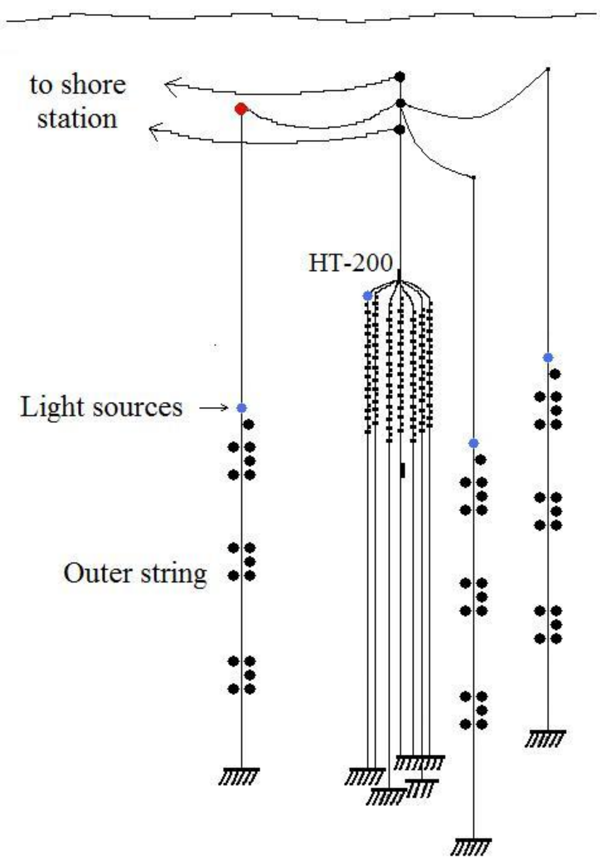

Fig. 1. Deep underwater neutrino telescope NT-200+ [3]. Red circle – triggering electronic module; blue circles – light sources, three of them fixed at distant strings and one attached to the one of NT-200 strings. NT-200 neutrino telescope [4] is shown in central part of the picture.

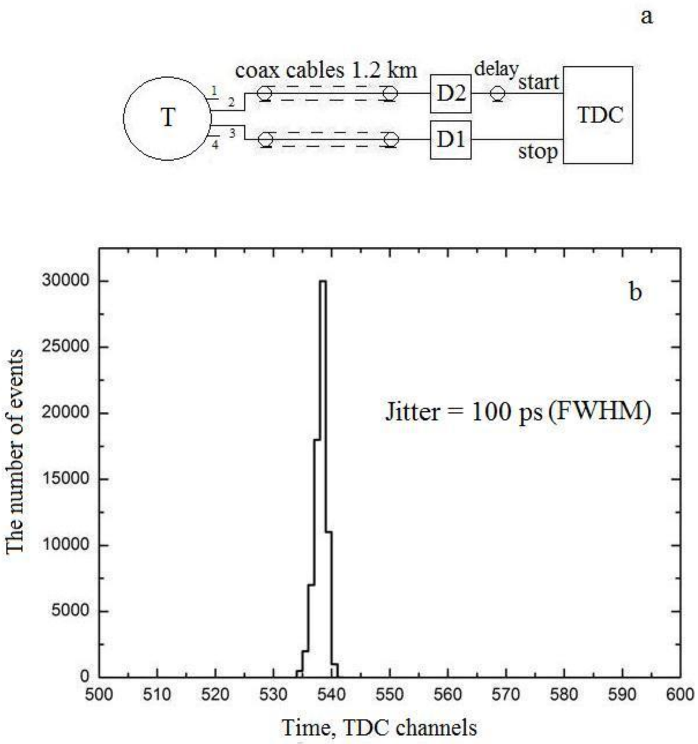

Fig. 2. The time jitter of triggering pulses after passing of 1.2 km long coaxial cables are less than 75 ps.

Deep underwater light sources modules (Light Beacons) have been developed especially for the lake Baikal neutrino experiments [1, 2]. They are based on a matrix of ultra bright blue InGaN/GaN LEDs and an avalanche transistor driver. The electrical scheme of the driver is shown in fig.3. The driver encorporate 5 individual drivers for each LED of the matrix. Each river exploits avalanche breakdown of an avalanche transistor (FMMT415 produced by ZETEX) discharging small capacitor (5-10 pF). The LEDs are NSPB500S produced by NICHIA CHEMICAL LTD. IN all drivers transistors emitter circuits are equipped with a tail canceling RL filter. Finally all drivers are switched in parallel froming matrix. In fig.4 (left) the light emission kinetics of an individual LED from the matrix and of the whole matrix measured by fast PMT (XP2020) are shown. To measure light pulses shape of individual LED all other LEDs of the matrix were masked and the time correlated single photon counting technique [8] was used. One can see from the figure that the light pulses shapes of LEDs are very similar. The light pulse shape of the whole matrix is practically the same as for an individual LED. The light pulse width of an individual LED and of the whole matrix is 1.8 ns (fwhm). More simple design possible with a matrix incorporating a single driver for 5 LEDs switched in parallel. In this case more powerful transistor driver (two avalanche transistors switched consecutively) is needed: light pulse width is wider (2.5 ns) with higher light yield [5, 7]. The photograph of the light sources is shown in the right part of the fig.4.

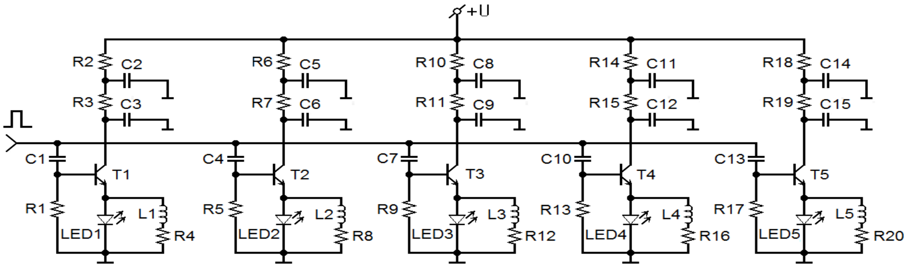

Fig.3. The electrical scheme of the light source.

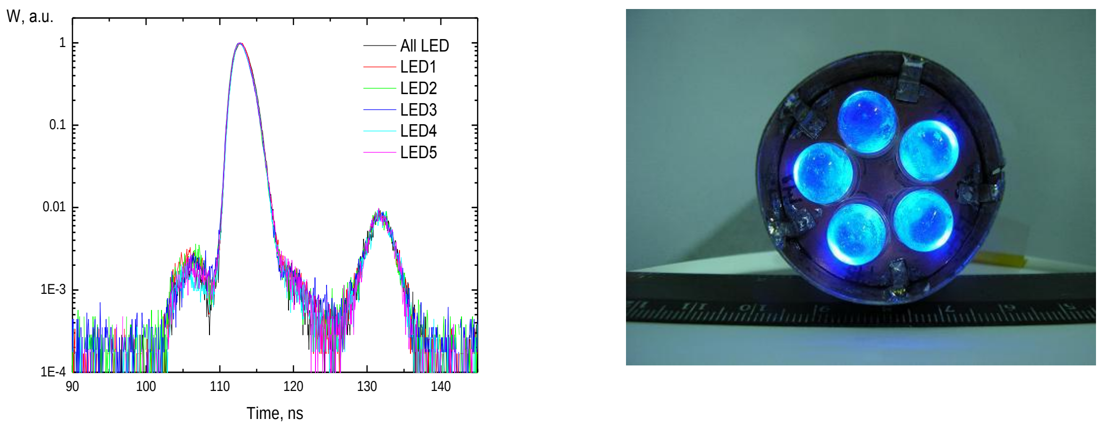

Fig.4. The light emission kinetics of an individual LED from the matrix (colored lines) and of the whole matrix (black line) measured by a fast PMT (XP2020).

There is a plethora of ultra bright blue LEDs in the market. Unfortunately not so many types of the LEDs demonstrate fast light emission kinetics. It was shown in [5] the “old” NICHIA LEDs are among the fastest LEDs. Extensive studies of the LEDs timing and light yield characteristics with the avalanche transistors drivers have been carried out in our group. The studies shows that the light yields of light sources based on such LEDs are about 10^9 photons per pulse with 1-2 ns pulse width. The long term stability is very high. The light yield and pulse width don’t deteriorate even after 10^{10} of total pulses running through LEDs at current pules of 2 A. As for temperature stability the light yield changes by 7% in temperature range of $-3^0 \div +45^0$C [5]. Although in case of neutrino experiments at the lake Baikal the temperature at the depth of ~1km is very stable. There are good alternatives to the “old” NICHIA and KINGBRIGHT LEDs: LDBK13633L6, YM-BV5S15N and GNL3014BC produced by LIGITEK, YolDal and G-nor companies correspondingly. The last one is very promising. To compare data of the “new” NICHIA and KINGBRIGHT LEDs are listed in the table too.

In fig.5 one can see one of the light source modules already fixed at NT-200+ cable and ready for final deployment. A bundle of plastic fibers attached to the light source module is clearly seen.

Fig. 5. The light source modules fixed at NT-200+ cable; ready for the final deployment.

4. Timing calibration of Cherenkov EAS arrays.

The TUNKA-133 EAS Cherenkov Array has been installed in the fall of 2009 [6]. The main physics goals of the experiment are studies of energy spectrum and mass composition of primary cosmic rays in the energy range of 10^{15}-10^{18} eV. The array consists of 175 wide angle optical detectors spread over ~ 3 km^2 geometric area and grouped into 19 clusters with 7 optical detectors in each cluster. 6 optical detectors of each cluster are arranged hexagonally and one detector is in the cluster's center. Each optical detector is equipped with remotely controlled fast LED driver with ultra bright blue GNL-3014BC LED. This LED driver is fixed near optical detector's PMT and used mainly for amplitude calibrations of the optical detectors. The LED driver provides light yield changeable in a wide range of 0-10^9 photons per pulse and pulse width of 3-10 ns, it should be noted here that it is possible to use them for timing calibration with help of high quality clock system.

The advent of ultra bright InGaN/GaN blue, violet and UV LEDs provides wide opportunities for development of calibration light sources for Cherenkov and scintillator detectors. Relatively new high power blue LEDs open new possibilities for design of Cherenkov detectors calibration systems. They are very bright and can withstand up to 1 A DC current. For the TUNKA-133 experiment we have developed powerful nanosecond light source based on high power LED XR7090 produced by Cree Company. The maximum of light emission spectrum of the LED is reached at 450 nm, so called "Royal Blue" LED. To get high light yield of the light source staying still in a few nanoseconds time domain the LED is driven by specially designed driver, fig. 6 (left) using a pair of avalanche transistors ZTX415 switched consecutively. A positive triggering pulse causes consecutive avalanche breakdowns of the transistors which discharge C_2 capacitor (C_2=47 pF) through high power LED providing nanosecond pulses of high light yield. The driver is triggered by a positive pulse with amplitude of ≥ 3 V. The light source is stable over wide range of repetition rate up to 1 MHz, although in the calibration system of the TUNKA experiment the rate is quite low -~5 Hz.

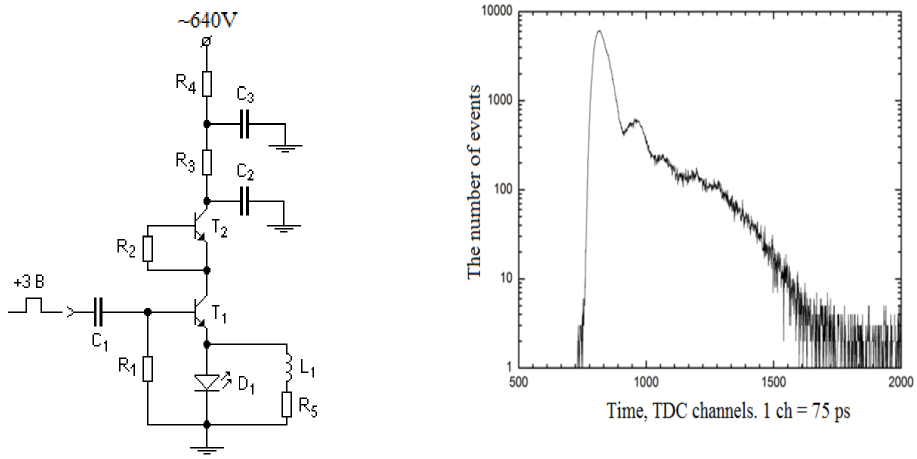

Fig. 6. Light source based on high power LED source (left); light emission kinetics of the light source (right.)

The light yield of the light source measured by an integrating sphere is ~10^{12} photons per pulse [2, 7]. The light emission kinetics of the light source was measured by time correlated single photon counting technique (TCSPCT) [8] and shown in fig. 6 (right). Fast and slow components of the light emission kinetics are clearly seen. The substantial contribution to the total light yield belongs to the fast component. The width of light pulses of the source is ~3.5 ns (FWHM). The light source emits photons into 100° full angle. The LED driver enclosed into a 40×40×25 mm^3 size metallic box.

Two approaches have been conceived to make time synchronization of the TUNKA-133 array’s optical detectors using above described light source. In this approach the light source is fixed on a helium balloon or a pilotless helicopter and raised at the height of ~400 m above the array. In this case one need to use GPS units and XBee radio units to know with good accuracy coordinates of the light source. In this approach it is enough to use only one light source because the light yield of the source and its emission angular distribution allow to illuminate from 400 m height all optical detectors of the array. Implementation of the approach is hindered by the fact that so far it’s unclear with which precision the coordinates of the light source on the balloon or helicopter can be maintained. Another shortcoming of the approach is its considerable price.

Based on the above described light source we have developed a system for calibration of the TUNKA-133 array using a pole (2-3 m long) or toy helicopter. The scheme of the system is presented in figure 7. The system is equipped with a pulse generator with repetition rate of 5 Hz and power supply with batteries. The total weight of the system should be no more than 1 kg.

The optical detectors of the array have 50° half angle of angular acceptance [9]. So, in case of pole there is a necessity to use light reflectors attached to the edge of each optical detector. Moreover for this approach we have developed a complex light source consisting of 4 light sources identical to the one described in fig. 6. All sources are fixed on one plate orthogonally to their neighbors. So, in such geometry the whole source emits photons into 2π angle in azimuth. All individual sources are triggered simultaneously from one pulse generator. The light sources including cables and all other connections are tuned between themselves in such a way that the accuracy of simultaneousness of the light pulses from all individual light sources is better than 50 ps.

A variety of pilotless helicopters even toy ones are widely available nowdays. Some of them are capable to haul up our light source to the hight of 300-400 m allowing to illuminate the whole array.

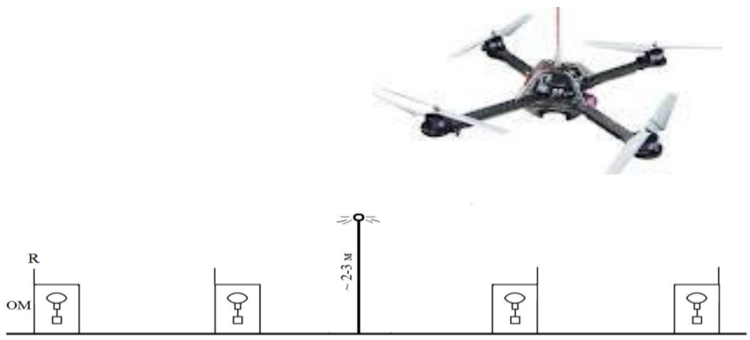

Fig.7. The scheme of the calibration system with a single light source fixed on a long pole or pilotless helicopter.

5. Conclusion.

New concepts presented here allow to developed inexpensive, robust and effective timing calibration systems for astroparticle experiments particularly for Cherenkov arrays like EAS Cherenkov and underwater Cherenkov arrays with sparsely distributed photon detctors.

6. Aknowledgements.

The work was supported by the Russian Federation Ministry of Education and Science (G/C 14.B25.31.0010), the Russian Foundation for Basic Research (Grants 13-02-92440-ASPERA and 13-03-12451-ofi-m). The authors are indebted very much to Dr. V.Ch. Lubsandorhzieva fo fruitful discussions and many invaluable advices.

References

[1] R.V. Vasiliev, E.E. Vyatchin, B.K. Lubsandorzhiev et al., Instr. and Exper. Tech. (2011) V. 54, № 4, P. 455.

[2] B.K. Lubsandorzhiev, R.V. Poleshuk, B.A.M. Shaibonov, Ye.E. Vyatchin, Nucl. Instrum. and Meth. A. 2009. V.602. P.220.

[3] B.K. Lubsandorzhiev et al. Nucl. Instrum. and Methods. 2003. V.A502. P.145.

[4] I.A. Belolaptikov et al., Astropart. Phys. 7, 138 (1997).

[5] B. Lubsandorzhiev, Y. Vyatchin. arXiv:0403018 [physics]. 2004.

[6] S.F. Berezhnev et al., Nucl. Instrum. and Meth. A. 2012. V.692. P.98.

[7] E.E. Vyatchin, PhD Thesis, INR Moscow, 2006.

[8] D. V. O'Connor, D.Philips, Time-Correlated Single Photon Counting, London, Academic Press, 1984.

[9] B.A. Antokhonov B.A. et al., Nucl. Instrum. and Meth. A. 2011. V.639. P.42