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The new large-sized scintillation charged particles detector for extensive air shower experiments at Tien-Shan.

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Abstract: A new type of scintillation detectors for the mountain cosmic ray complex *ATHLET* is designed in the Institute for High Energy Physics. The detector is implemented on the basis of 10 mm thick molded polystyrene plates in conjunction with wavelength shifting fibers. It has a 1x1 m^2 sensitive area, a $\sim$ 99% registration efficiency of a charged particle and a homogeneity of the scintillation light output better than 90%. Due to its relatively low mass and cost characteristics and the absence of an external high voltage power source it suits well for the use in wide-spread multi-channel extensive air shower installations.

Introduction.

The program of joint scientific investigations of the Russian Federation and Kazakhstan Republic anticipates creation of a new experimental complex *ATHLET* (Almaty THree-Level Technique) in northern Tien-Shan, in the vicinity of Almaty city [1] with the aim to study the properties of extensive air showers (EAS) in the energy range around the knee of primary cosmic ray spectrum (10^{15}-10^{18} eV). Constituent parts of the complex — three similar installations for registration of EAS particles — will be placed at the heights of 3340, 1750, and 850 m a.s.l. The total effective area of the shower installation only in the central part of the complex — at the Tien-Shan mountain station, 3340 m a.s.l. — is assumed to be of the order of 3 km^2, about 1000 separate scintillation detectors being necessary for the purpose.

Until recently, scintillation detectors used in EAS studies were based on registration of diffused light, which is unavoidable to ensure the independence of the registered intensity of scintillation flash on the point of particle passage [2]. Use of special diffusive reflectors causes enormous, up to two orders of magnitude, losses of scintillation quanta, which, in tern, result in the necessity to use the thick (5-10 cm) block scintillators. Not to mention the relatively expensive cost of these scintillators and the high resulting weight of a detector assembly (only the weight of such a scintillator without the housing, electronics etc is about 50-100 kg/m^2), they are quite sensitive not only to charged particles of the shower but also to the EAS γ-quanta. When passing from the intensity of scintillation signal to the particles number N_e the last circumstance demands insertion of complicated corrections which depend both on N_e and the distances between each particular detector and the shower axis. For the large shower installation with ~ 1000 modules elevated up to some hundred meters above the mean installation surface, this type of detectors is fully unfit.

At the same time, in last few years a tendency has appeared to apply in cosmic ray physics principles and methods elaborated in accelerator experiments. As for detectors of EAS particles, there exist proposals to use the thin plastic scintillators in conjunction with wavelength shifting bars [3] or fibers [4]. Beside the traditional photomultiplier tubes (PMT) using of newly developed avalanche photo-diodes for registering of scintillation pulses is proposed in [4, 5].

Hence, for the *ATHLET* installation complex it seems timely now to create a new particle detector starting from the modern technological principals. The technical requirements for such a detector should be the following:

- Detector must be sensitive to the particle fluxes about 1 m^{-2}, i.e. the effective area of a single detector must be about 1 m^2 and the registration efficiency of a relativistic charged particle 95% or better.
- The net weight of the 1 m^2 scintillator must be below 10 kg and the total weight of detector assembly must not exceed 30 kg.
- Detector must be free from the influence of the EAS γ-radiation; this means that the scintillator thickness can't exceed 1 cm.
- Detector must possess a high homogeneity of light collection (in the limits of $\pm10\%$, independent of the position of particle's trajectory).
- Detector must have an in-build amplitude-to-digital converter (ADC); all information exchange with outer world must be performed by the digital signals.
- This ADC must possess a wide dynamical range (about 2^{12}-2^{14}): an ideal scintillation detector must effectively register the fact of the passage of a single charged particle and, at the same time, ensure the possibility to measure the flows in the vicinity of EAS core, where the numbers of registered particles would be in the range of 10^5-10^6.
- Detector must satisfy the conditions of outdoor exploitation, in particularly, feeding the all high-voltage circuitry must be performed from the detector's internal voltage multiplier, only the low-voltage power cables could be connected from outside.
- The number of outer cables must be as little as possible; connection with the registration center should be performed by a single cable line used for both power feeding and the data transfer.
- Number of photo-electrons from a single minimum ionization particle (MIP) must be $\geq$20 (this is an empirical requirement for the steady long-term operation of a scintillation detector under the realistic conditions).

The plastic scintillator.

To satisfy the above requirements a new type of scintillation detectors was designed in collaboration of Tien-Shan mountain station's research team with the Institute for High Energy Physics (IHEP) in Protvino. The basic design principles of this detector are shown in figure 1.

As an active medium are used molded polystyrene scintillation plates of the SC-301 type produced in IHEP. The basic characteristics of these plates are the following: lateral sizes 20x20 cm^2, thickness 0.5 cm^2, light output about 60% of that of anthracene, maximum of luminescent spectrum around the wavelength 420 nm and the mean emission time τ_s=2.3 ns [6]. Scintillation plates are put without gaps in two layers, 25 plates per each.

Each polystyrene plate has four lengthwise grooves 2.5 mm deep and 1.2 mm wide, pressed on its upper surface during the molding process. The grooves constitute channels for placement of wavelength shifting (WLS) fibers when the plates are put together. The fibers, which are of the Y11 type with double cladding [7], 1.0-1.2 mm in diameter, are put inside the grooves which afterwards are coated with BC-600 type epoxy resin. Step distance between the grooves is 36 mm; total amount of the fibers in the whole assembly is 20. The fibers re-emit ultraviolet scintillation light in the 476 nm spectrum range and transmit them to a photomultiplier tube.

The method of the setting of WLS fibers inside the polystyrene scintillator is the following: each of the fibers, nearly double in the length as scintillation assembly is, is put in two adjacent grooves making a loop at the one side of assembly. At the other side, where a photomultiplier tube (PMT) is placed, the fibers are faked in the coils compensating the length differences of their stretched parts. (All the fibers have strictly the same length, which is necessary to achieve a time resolution of scintillation pulse registration of the order of

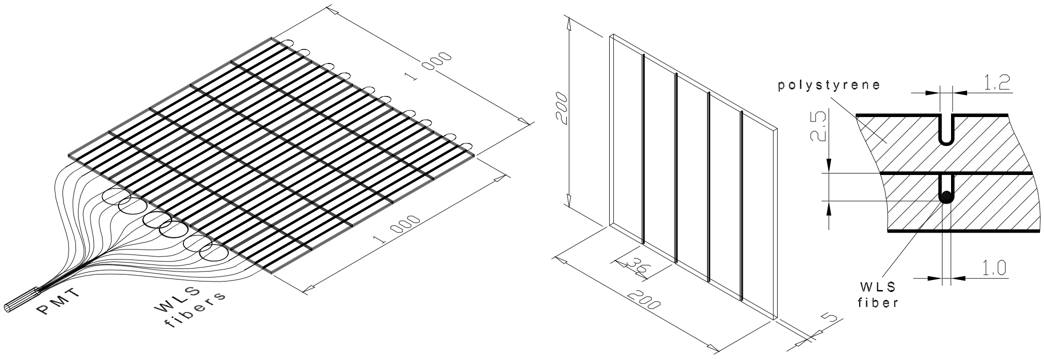

Figure 1: At the left: general view of the scintillation detector assembly; in the middle: the single molded polystyrene scintillation plate of the SC-301 type; at the right: placement of WLS fibers inside the polystyrene scintillator. Dimensions are measured in mm.

some nanoseconds). Free ends of the fibers are put together into a bundle impregnated with epoxy resin. After consolidation of the resin the edges of the fibers where cut, polished and pressed to the photocathode of a FEU115M type PMT [8]. The maximum lateral cross-section of the fiber bundle can't exceed the diameter of the active photocathode region (about 25 mm). From the outside the whole assembly is wrapped by a combination of reflective materials: writing paper (around the nearest to PMT scintillator's side), Mylar with aluminum coating (in the middle) and the Tyvek paper (around the farthest side). The test measurements have shown, that such combination of the method of WLS fibers setting and a combined outer reflector ensures a light collection homogeneity over the whole scintillator surface not worse than 5% both in the along-the-fibers and in perpendicular directions.

The system of high-voltage feeding.

Recently, the schemes of PMT feeding based on the principle of Cockroft-Walton voltage multiplier [9] have gained a wide distribution. This is a consequence both of the modern progress in development of the necessary elemental base and the intrinsic merits of the scheme: low power consumption coupled with high dynodes current, low voltage of external power source, possibility of the individual tuning of amplification in different channels. For detectors, destined for using in outdoor conditions, the multiplier scheme seems to be the most appropriate.

The system of PMT feeding of the considered particle detector consists of a diode-capacitance voltage multiplier and an in-build control unit which, firstly, permits to change output voltage in the range of 1–2 kV and, secondly, keeps its stability at the level about 10^{-3}. The scheme ensures a 20%-stability of the amplitude of output signals by short-time overloads of anode current up to 1 mA.

The usual scheme of PMT feeding assumes that the photocathode is connected to the negative high voltage potential while the anode is kept under potential of the ground. Requirements of a low-noise PMT operation in our case being essentially important, we use another feeding scheme, with a grounded photocathode and a positive high potential at the anode. In such a case all PMT elements which carry information signals (dynode system so as the anode) occur to be shielded from external interferences by PMT body.

The whole in-build electronics of scintillation detector is powered by the two external low-voltage sources, +12V and -12V. Hence, detector's connections with outer world are limited to a pair of shielded coaxial cables which are necessary to carry these voltages. Simultaneously, the same cables may be used for transmission of the control and information signals both to and from the detector.

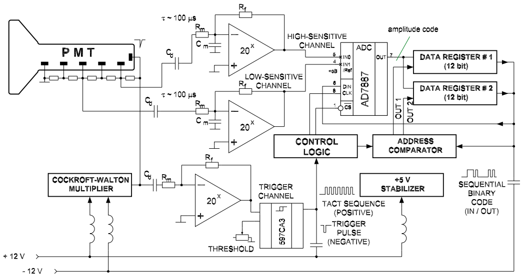

Figure 2: Block diagram of the in-build detector's electronics.

The amplitude-to-digital conversion and data collection principles.

A simplified block diagram of the internal electronics which is to be build inside each detector's housing is shown in figure 2.

The scintillation detector must have several ways of information output. Firstly, the signal from the PMT anode will be used for elaboration of a shower trigger by the means of a fast amplitude discriminator. Linearity of this channel permit to measure particle flows in the range of 1-100 m^{-2}. A trigger pulse generated by every particular scintillator will be transmitted via the one of the power feeding cables to the all other detectors of shower system. The same cable is used also for transmission of the synchronization tact sequence which is necessary for operation of the integral amplitude-to-digital conversion (ADC) chips of the AD7887 type [10].

The trigger initiates amplitude analysis of the signals in two another information channels: the pulses taken from the last (12-th) dynode of PMT and those from its intermediate 7-th dynode. Both signals must be analyzed in the amplitude range from 0 to 2–5 V, preserving a good linearity of the output pulse. Hence, three information channels in the sum should cover dynamical range of the values of particle density about 10^5–10^6 m^{-2}.

The 12-bit codes of pulse amplitudes which were present at the two inputs of an ADC chip in the moment of trigger arrival are stored in a pair of digital registers where they may be read from sequentially at the commands of a control computer. Transmition of sequential data codes succeds through another feeding cable (-12V in figure 2) which operates bi-directionally: the control computer generates a sequence of address code, which specifies the number of a particular detector to be seen, in all in-line detectors of the system these codes are simultaneously compared with their pre-set internal addresses and detector whose address coincides with this code begins transfer of the content of its data registers. The whole process of data exchange is synchronized by the tact sequence transmitted to the system via the +12V feeding cable.

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