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THE POSSIBILITIES OF CONSTRUCTING A VERY BIG CHERENKOV DETECTOR WITH WAVELENGTH SHIFTERS

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INTRODUCTION

Presently, the investigation of nucleon stability is one of the central physical problems. Due to this, there is a number of suggestions on the development of low-background facilities with large volume of detecting substance. Thus, there is a plan to construct under the Mont Blanc/3/ a detector with alternating iron and gas counter layers with the initial weight of 150 ton and later 1000 ton. Nevertheless, the largest volumes can be obtained only in water Cherenkov detectors/1,2/ . A water detector with a volume of 8 thousand ton (20x20x20 m^3) is under construction, presently. It will enable one probably to estimate the proton lifetime at the level of 10^{33} years/1/.

The concept of the experiment is as follows: In 50% of events the $p \to e^+ + \pi^o$ decay is expected. The e^+ and π^o flying apart in the opposite directions are registered over the Cherenkov radiation. Each of the facets has a matrix of photomultipliers 20x20 = 400 pieces. By the authors calculation for e^+ , the Cherenkov ring ∅ = 18 m, 2.5 m wide, will enable the photomultiplier with 5″ diameter to produce 1.6 photoelectrons on the average. The amplitude-to-digital and time-to-digital converters allow one to estimate the total number of photoelectrons (300 photoelectrons per 1 proton decay) and to reconstruct the stereopicture. The possibility of selecting events by their energy with the resolution 20% and angular resolution $\Lambda\theta = 15^\circ$ is expected. Moreover, the authors expect to suppress substantially the contribution from the background including the one from the main interferring process $v_e N \to e \Lambda \xrightarrow{} \pi^o$. The fiducial volume is assumed to be 16x16x16 m^3 , i.e., it is 2 meters away from the photomultipliers. This is necessary to accomodate the free paths of decay products and to absorb the gamma rays and the neutrons from spontaneous fission of uranium and thorium. The problem of the background and of the reliability of decay events interpretation (in case such events will appear) can be finally solved by experiment only. The anticoincidence screens in such facilities would have simplify significantly the experiment. Besides, it would have been useful to design this facility not only for nucleon decay

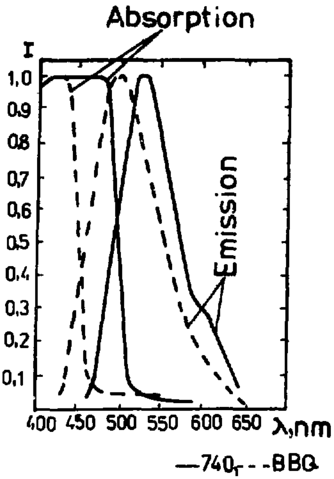

Fig. 1.

searches but also for experiments with cosmic neutrino. But the spectrometry of events with the energy yield of tens of MeV is unfavourable due to strong nonuniformity in the sensitiveness of light collecting facets. With this regard we have used as a basis another version of light collecting which uses the wavelength shifters /4,5/ . It increases also the sensitiveness itself. For collecting the Cherenkov light plastic shifters of the size 140x25x0.6 cm^3 with absorption length L = = 2.3 m have been used /6/. However, it is necessary to have $\sim$ 2400 m^2 of shifters in our case which seems excessive and too expensive if plastic is used. This explains the interest to shifters with liquid solvents.

WAVELENGTH SHIFTERS

Light collecting with wavelength shifters has the following basis. The substance in the shifter absorbs the short wave light emission and emits a longer wave one, doing it almost isotropically. Due to this, in cases when the mixer's reflective index (n_2) exceeds the refractive index of the light emitting medium (n_1), it turns possible to direct light through the light-guide towards the photomultiplier by using total internal reflection. The area of the photomultiplier must be approximately equal to the light-guide cross section. The light in this case decreases by one order but the light collecting surface itself can be larger by two orders.

The BBQ dissolved in plastic has been used in ref./7/ as a shifter for constructing a scintillation calorimeter. The dimensions of the plates are 2x4x150 cm. To form a medium with another reflection index air gap has been left between the plates and the scintillator. For the additional absorp-

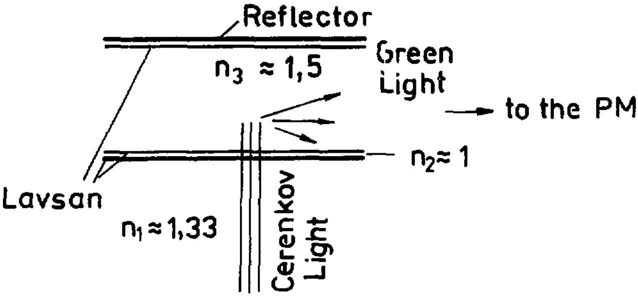

Fig.2.

tion of initial light the three sides of the plastic rod have been covered with aluminium foil contacting physically but not optically with plastic. At the BBQ concentration of 90 mg per 1 litre has been converted more than 95% of the initial light. The length of light absorbtion of the shifter has been 3 meters and as the author thinks they have collected approximately one half of the light emitted from the shifter by using a mirror at the end opposite to the photomultiplier. The spectra of light absorbtion and emission are presented (for BBQ) in Fig.1. BBQ delay time is 10 ns[8]. We would have been better satisfied with another spectrum shifter "green 740" (indicated by the straight line in Fig.1). The estimated delay time for it is very small (~ 1 ns)[9]. The transmittance of 740 is not less than that of BBQ. This follows both from Fig.1 and from the data of refs.[8,9] . Reference [8] shows that the transmittance of the shifter yellow 540 is the same as of BBQ; and from ref.[9] it follows that the 540 is worse in transmittance than the 740. For the 740 shifter the maximum of the emission spectrum is near the maximum of the spectra of such photomultipliers as PM-49 (D = 15 cm) and PM-95 (D = 16 cm). The expected losses of quantum yield due to the displacement of the shifters spectrum maximum to the right will be ~ 30%. But for the Cherenkov light absorbtion such displacement is favourable.

The greatest dimensions of light collecting facets can be obtained by using liquid wavelength shifters with refraction index around $n = 1.5$ which are at the same time cheaper and more accessible. But the problem is in the fact that the walls get obscure with time because of the water-diffusion[10].

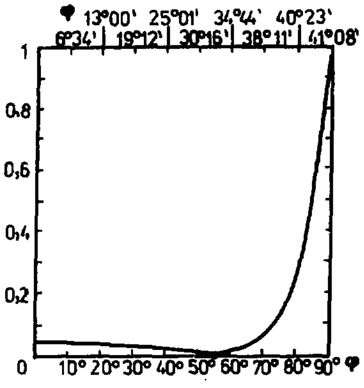

Fig.3.

Nevertheless, creating giant detectors one can rely only on liquid shifters. To avoid the diffusion of liquids from one medium into another we suggest to use two walls with no optical contact between them (see Fig.2). Between these walls there is gas similar to CO_2 or freon, and sometimes this gas is blown through this space. The Cherenkov light penetrates into the shifter through the double lavsan (milar) films. The best thing is to use the scintillation liquids which can simultaneously ensure the anticoincidence screen by registering events with intense localized light flashes. The facility needs the shifters shaped into blocks 5 m (may by 3 m) long, 0.7 m wide and 2.3 cm thick. Of course, the absorbtion length of green light will be long enough if lavsan films have no creases.

THE CONDITIONS OF CHERENKOV LIGHT COLLECTING

According to ref.[11] at complete collecting of the Cherenkov light on the antimony cesium photocathode with sensitivity of 80 ma/lm, every centimeter of the electron path on water forms 67 ph.e. It is easy to notice that for the PM with 5" diameter, 1 m spacing and e^+ path 2.5 meter the number of photoelectrons will appear to be 170 which is as much as the number assumed in ref.[1]. This calculation has been made, evidently, for very clear water ($L \sim 40$ m). For the ordinary rain water $L = 20$ m starting from ~ 360 nm. For obtaining clear water the nuclear filters should be very effective. Their productivity is quite sufficient for filtration at the level of light wave lengths and at even smaller levels. It is worth mentioning that here we can count on practically complete removal of admixture containing uranium and thorium which are the source of the low-energy radioactive background.

The Cherenkov light coming from water passes through the air into the shifter much better than scintillation light since the Cherenkov light is longitudinaley polarized. Figure 3 illustrates the dependence of reflection coefficient on the angle of incidence at the refraction index 1.5; the upper scale is the transition from radiator into the air, the lower scale is the reverse transition[12].

The upper scale in Fig.3 should be corrected taking into account the fact that water has a smaller refraction index and the angle of complete internal reflection ϕ_n will be not 41°08' but 48°40'. The decrease of the refraction index will only result in the decrease of the quantity of reflected light. It is evident that this yield is of the order of several per cent with the exception of a very narrow range of angles (~ 1°) near ϕ_n.

Let the set of block-shifters form a perfect cube. If the particle track is perpendicular then a perfect ring of light will appear on this side. At particle deflection from the perpendicular direction within θ = 0+7°20' the Cherenkov ring changes into the ellipsoid and with growing θ the region of light beam crossing with the cube side grows. If $\theta > 7°20'$ the light after reflection reaches the neighbouring cube side at $90° - \phi$ where it is registered. Thus, a part of the ellipsoid is as if torn off and transmitted to another cube side. As a result we obtain two light "horse shoes". According to our estimations the change of the particle incident angle from 7°20' to 15 results in the transmittance to another cube side of 10% of light. Thus, the ratio of light quntities in the "horse shoes" adds to the information on the picture shape the data on the incidence angle of particle path. Hence, the dissection of light ellips which seems to be a drawback can be usefully employed.

FORMING OF SIGNALS IN THE COUNTERS

Approximately half of registered light occurs to be lost due to changes of the photon spectrum and to the processes in the shifter. Analogously to [7,9] we assume that a quarter of light will go towards the PM, another quarter will reach the opposite end of the block and will be reflected there (K_{ref} = = 0.9). Taking into account the losses of light in the light guide (also liquid) and other reasons we can accept that 10% of the charge, if compared with complete collecting of Cherenkov photons, is formed in the straight wave in the PM. In this case the absorbtion by the block is not taken into account. Assume that the block length $l = 2L$. Then the total

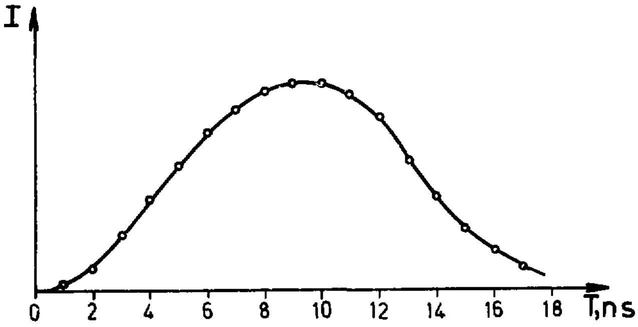

Fig.4.

charge Q_1 from the direct and reflected wave for the points $x_1^{\circ} = 0$, $x_1' = L$ and $x_1'' = 2L$ will be respectively 10.2; 4.1 and 2.3%. We position the PMs at the opposite ends of two neighbouring blocks, i.e., $x_2 = 2L - x_1$. If the intensities of Cherenkov light for both blocks are not much different then the following ratio $6.2\% > \frac{Q_1+Q_2}{2} > 4.1\%$ is valid. Thus the resulting average light collecting will be 5.2%, i.e., for the above case (the diameter of Cherenkov ring being 18 m) there will be not 1.6 but 8.2 photoelectrons per 1 m^2 . The region of Cherenkov light impact with the block is defined by the time which is necessary for light to pass along the block. Certainly, the non-identity of paths of separate photons decreases the time resolution but not too much, since with the growth of the path the photons flying at large angles and reflected for a greater number of times are out first. Note, that the difference in photon paths appears only at large angles and within 30° it is comparatively small ($1/\cos 30° = 1.15$). The accuracy of time measurements decreases with the increase of delay time of shifters and increases with the growth of photon number. To illustrate this we present in Fig.4 the estimated curve of charge density distribution in time for the following particular case. Cherenkov light comes in at 1.8-3.9 m from the PM. At the block width of 0.75 m, 15 photoelectrons will be formed. Light will reach the far edge 7 ns earlier than the near one due to the slope of Cherenkov radiation. The delay time is 5 ns. Light comes to the PM isotropically at an angle of

$0 \div 45^\circ$ (this is assumed to simplify the calculations). Figure 4 shows that in case there appear ≥ 10 photoelectrons in the PN, it is possible in principle to expect the time accuracy to be ~ 2 ns; and when taking into account the photoelectron statistics, ~ 4 ns, which corresponds to the space resolution $\Delta = 80$ cm. $\Delta = 1$ m would have been quite acceptable too.

Let the average Δ be equal to 80 cm. On defining the spot of shifter substance excitation it is possible to make a correction of a collected charge by taking into account the photon absorbtion in this substance. Whithout this, in case we sum up the data from all the blocks the maximum spread of the charge will be $\frac{6,2-4,1}{0,5(6,2+4,1)} = 0,4$. As a result of a simple correction for two neighbouring blocks this quantity becomes $\ell/2\Delta = 4$ times smaller. Thus we obtain the distribution curve of space sensitivity, the base width of which is 0.1 of the mean value, i.e., the resolution (FWHM) will not exceed 5%. Of course, it is necessary to make an individual correction for the blocks which cross the Cherenkov ring far from the centre and their resolution will grow twice worser. It should be noted that a more accurate correction for the cube side on which the Cherenkov ring is formed, becomes possible on taking into account the data from all the blocks.

Note, that with the decreasing outer diameter of the ring the accuracy of defining the spot of convertion increases in the shifter with the number of photoelectrons per one block.

THE DETECTOR DESIGN

The diagram in Fig.5 shows the cut away of the detector in the horizontal plane. The shifting blocks with PMs are placed into the water 2 m away from the concrete walls, i.e., 5.5 radiation lengths away. This exterminates reliably (makes 260 times smaller) the gamma-ray background from the rocks and from the walls and the neutron background (makes 10^9 smaller at $E_h = 6$ MeV /18/). Four (six) blocks constitute the cube linear dimensions 20 m. Due to design considerations the blocks have a 10 inclination to the plane of the facet. The neighbouring vertical and horizontal blocks are positioned in such a way that 100% of Cherenkov light gets into the mixer substance. All in all there are 720 (1080) blocks and PMs. Simultaneously, the shifter can be used for anticoincidences. According to the estimations, the average charge from cosmic

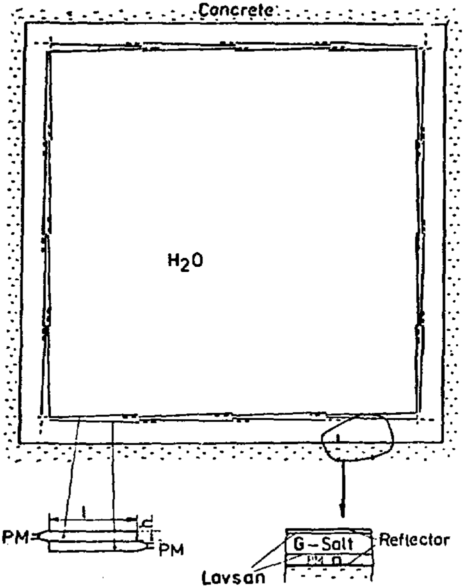

Fig.5.

muons is more than twice larger than the charge referred to any sight with dimensions 0.8x0.8 m^2 which can appear in the N-decay.

The expected inefficiency of these anticoincidences is $10^{-2}-10^{-3}$. But these are along anticoincidences. Logical anticoincidences are also stipulated by the insertion of approximately 30 PMs between the blocks and the walls for every facet but the bottom one (see Fig.5, bottom). The walls and the blocks are covered with reflecting substance. To prevent the blocks and PMs from interferring with light collecting they are fixed to the suspenders. If the light is distributed isotropically along the photocathods plane the PMs will registrate 10 photoelectrons in case the relativistic particle path is 1.5 m. The number of photoelectrons can increase repeatedly owing to reflectors. At the reflection coefficient 0.9 it would have become five times bigger.

The number of photoelectrons can be significantly increased (by 4.4 times on the maximum) by placing water in the gaps into lavsan sacks and adding some G-salt. This salt has rather complex molecules and its diffusion through the walls is insignificant. By the way, the absorbtion spectrum of G-salt lies below 400 nm and we do not exclude the possibility of introducing the G-salt into the substance through the whole detector volume in order to increase the light collecting in this detector twofold or threefold. Here the wave band 400-500 nm will still produce Cherenkov rings and this will occur ~20 ns on the average early because of the G-salt de-excitation delay.

Thus, in principle, every anticoincidence event can product up to 200 photoelectrons and more (at the inclined muon trajectories). But 20 p.e. are already enough to provide the highly efficient anticoincidences. We can apply a low enough threshold for PM triggering. In this case the basic noises will be cut-off. The probability of appearing of less than 3 photoelectrons at a mean value number 20 will be only $3 \cdot 10^{-7}$.

METHODIC CAPABILITIES OF THE FACILITY

Like it has been already mentioned the sensitivity of the facility /1/ changes in stages in 1 m. It is highly probable that in the case of particles with short paths the Cherenkov light will not reach the PMs at all or there will take place large amplitude fluctuations. Due to this such detector, for instance, is not so good for registrating neutrino flashes originating in the gravitational collapse of stars especially if the spectrum of positrons from $\nu_e + p \rightarrow n + e^+$ is about 10–30 MeV.

In the proposed version a positron with E = 10 MeV will give on the average 15 photoelectrons. This will ensure their reliable registration. The information on the neutrino mass can be obtain through comparing the time of arrival of neutrino of different energies. The great mass of the water detector (10^{33} protons) will enable not only to observe constantly all our galaxy but also the closest to us galaxies such as Great and Small Magellanic Clouds the distance to which is three times as big as the linear dimensions of our galaxy.

The described detector is of large and uniform mass and is convenient for observing the processes taking place inside the detector when it is used as a target. Thus, for example, one can observe in this detector the muon decay with delayed electron production (if the energy of the electron > 5 MeV) which can be used in particular for the searches of intermediate meson in processes with cosmic neutrino.

The detector ensures favourable conditions for observing the $\pi \rightarrow \mu \rightarrow e$ decay which enable the accurate selection of muonic photonuclear interactions by detecting the $\pi^{\pm}$ against the background from the showers produced in bremsstrahlung.

It is also possible to consider the possibilities of registrating the solar neutrino with the energy exceeding 6 MeV, when there appear more than 10 photoelectrons on the average. By defining the shape of the Cherenkov light picture and of the photoelectron appearance time distribution with respect to each other one can define the point of neutrino interaction and plot the corresponding results of observation for different detector coordinates. In the central part of the detector (weight 1-2 ton) protected with a 4-5 meter layer of water the background from the rocks and from the walls will be negligibly small and there can remain perhaps only the background from ^{40}K producing a 2.7 MeV electron. The statistical probability for an electron with such energy to give the same number of photoelectrons as the one with $E \geq 6$ MeV makes $p = 2 \cdot 10^{-2}$, i.e., the background will be strongly suppressed. At the boron neutrino flux 10^6 $cm^{-2}sec^{-1}$ it is expected to obtain 300-600 required events during one year. The number of events will remain acceptable for energy losses $E \geq 10$ MeV and P for these losses will be equal to $2 \cdot 10^{-4}$, i.e., there is a certain possibility to registrate the neutrino coming from the Sun.

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