A simple Cherenkov detector for educational purposes

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Cherenkov detectors are in use today in small experiments as well as modern ones as those at the LHC. This short note is about the construction of a small Cherenkov detector with limited resources, which could be used to observe the cosmic rays. The Cherenkov light obtained in this particular detector is read with a photo multiplier tube and its signal is observed on an oscilloscope. The detector construction can be achieved by relatively simple means and can be used as an educational tool.
I. INTRODUCTION

Cherenkov radiation is electromagnetic radiation when a charged particle passes through a dielectric medium at a speed greater than the speed of light in that medium. When a charged particle travels, it disturbs the electric field in the medium and medium becomes electrically polarized. If a charged particle has enough speed, a coherent shockwave is emitted. The similar analogy can be thought as a sonic boom of a supersonic aircraft. Cherenkov emitting angle can be easily expressed as \( \cos(\theta_c) = \frac{1}{n} \), where \( n \) is the refractive index of the material and \( \beta = \frac{v}{c} \). If \( \beta \) is greater than \( 1/n \), Cherenkov radiation will be emitted as shown in Fig. 1 left side. Using relativistic kinematics, the threshold energy of Cherenkov radiation can be given by:

\[
E_{\text{threshold}}(n,m) = m c^2 \sqrt{n^2 - 1}
\]

At this energy, the Cherenkov light is emitted along the path of the particle. The same figure right side contains the blueish Cherenkov light observed at the Reed Research Reactor originating from fast electrons. In case of \( \Delta n = n - 1 \ll 1 \) approximation, the threshold energy can be rewritten as

\[
E_{\text{threshold}}(n,m) = m c^2 \sqrt{2\Delta n}
\]

Therefore, such a detector could be used to trigger on various particles at various energies for small experiments or for educational purposes, depending on the radiation medium.

II. DETECTOR DESIGN AND CONSTRUCTION

The simplest Cherenkov detector would consist of a barrel with enough volume to produce Cherenkov light and reflective inner surfaces to channel that light into photon counting detectors. In high energy physics such a detector would be a Photo Multiplier Tube (PMT) requiring about 1.5-2 kV for operation. The speed of light in the material to be installed into the barrel has to be smaller than the vacuum value \( c \) to permit Cherenkov radiation. For example, water \( (v_c = 0.75c) \) would be a cheap and easily accessible material allowing detection of Cherenkov light for cosmic muons with energy larger than 160 MeV. However, using CO2 (Air) would allow detection of cosmic muons of energy threshold of 3.52 (4.4) GeV.

To build the simplest possible detector in the cheapest possible way, possible barrel alternatives have been considered such as a beer keg and a large water dispenser. The simplest solution was found to be a 20L volume plastic trash bin since it permits about 50 cm water depth, large enough to produce Cherenkov light. The inner side of the bin was covered with kitchen grade aluminum foils to improve its reflectivity. A view of the Al covered bin can be seen in Fig. 2. The available PMTs were R7525HA-2 from Hamamatsu with 25mm photocathode diameter and requiring about 1500V for proper operation. Since these PMTs can not operate in water, a simple setup from foam and cardboard was prepared to keep the single PMT above the water level. The signal output from the PMT base can be readout directly with an oscilloscope without needing a pre-amplifier circuit. The light tightness of the finished product was provided by multiple layers of black felt blankets.
The detector was first tested with air inside the bin to have an understanding of the background values. With a threshold as low as -7.2 mV, the background rate is measured to be less than 10Hz. This value is consistent with a background rate originating from the PMT’s own dark current and from cosmic rays passing through the PMT window. A screenshot from the oscilloscope in accumulating display mode can be seen in Fig. 3.

After determination of the rate and pulse height of the background events, the bin was filled with tap water providing a water height of about 50cm as seen in Fig. 4 left side. The signal threshold was set to -30mV eliminating most of the backgrounds. The solid line pulse in the same figure right side acquired after about 10 mins is consistent with a cosmic ray passing through the photocathode, both rate-wise and pulse height-wise which is about -60 mV.

The expected Cherenkov signal on the other hand has to be rarer and should have a much higher pulse height. Such an event was observed after about 15 mins as shown in Fig. 5. Here the pulse height is about -150 mV as expected from Cherenkov light from a high energy cosmic ray. It is difficult to further elaborate on the cosmic ray’s properties without calibrating the detector in a test beam. However, it is thought that by improving the quality of the inner
reflecting surfaces, i.e. by collecting more light, the sensitivity of the setup can be increased. Of course, adding at least one scintillator to the system and measuring the timing between the scintillator and Cherenkov would largely improve the setup.

IV. CONCLUSIONS AND OUTLOOK

Although this particular detector was produced with the minimum of investment, aiming a proof of the principle, a more developed detector using not tap water but Gadolinium doped pure water has been submitted to the Turkish Research and Technical Council, TUBITAK. The aim is to measure the anti-neutrino flux from the soon-to-be-build nuclear reactors in Turkey [4]. This current setup would be extremely useful for educational and demonstration purposes, if PMT, high voltage and oscilloscope requirements can be eased. For the first two, one could consider the utilization of Silicon photo multipliers. The last one can be matched by a small portable computer running an oscilloscope and display application. There are such low cost USB devices [5] and computers capable of running these [6]. With such a setup it would be possible to display the cosmic rays and measure their energies in real-time by adapting various materials with \( \epsilon > 1 \). Furthermore, if batteries can be used as both low voltage and high voltage power sources, the detector would become cable-independent, a major step for using it in particle physics education.
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