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Attenuation Length of light in the CHIPS-M Water Cherenkov Detector

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Abstract. The water at the proposed site of the CHIPS water Cherenkov detector has been studied to measure its attenuation length as a function of filtering time. A 3.2 m vertical column was filled with the water from the Wentworth Pit, proposed site of the CHIPS deployment. Results consistent with attenuation lengths of up to 100m have been observed at this wavelength with filtration and UV sterilization alone.

1. Introduction

The CHIPS (CHerenkov Detectors In PitS) R&D project will investigate a novel and very inexpensive water Cherenkov detector. Demonstration of a cost in the region of $200-$300k per kilo-ton (kt) is one of the goals of this R&D in order to realise mega-ton scale detectors in the future within realistic fiscal constraints. A prototype detector of between 3-5 kt of water is proposed for construction 7 milli-radians (mrad) off-axis in the NuMI neutrino beam, in a flooded mine pit 708 km from the neutrino source at Fermilab. The prototype detector will observe neutrinos via the detection of Cherenkov radiation produced by their interactions in the water inside the detector.

A major part of the cost saving in the CHIPS concept is achieved by enclosing the cleaned detector water volume in a lightweight, water- and light-tight containment vessel to be submerged in the Wentworth pit. The 60m depth provides an overburden of water to provide cosmic ray shielding at the same time as physically supporting the detector volume. The Cherenkov light from neutrino interaction remnants in the water will be collected by planes of 3" photomultiplier tubes (PMTs) positioned on the sides of the detector. The attenuation length of the Cherenkov light in the water must be long enough to ensure very little reduction from production point to PMT. The pit had once functioned as an open taconite mine and it is expected that the water will contain substantial suspended particulates. These can be removed by conventional filtering. The goal of this study was to understand whether, after filtering, the remaining dissolved solids in the water would provide significant attenuation to the light. In this case further treatment of the water, such as reverse osmosis or de-ionisation would be necessary, potentially leading to significant density differences between the inner and outer water. The

Figure 1. Photograph of the experimental setup in the laboratory to the left.

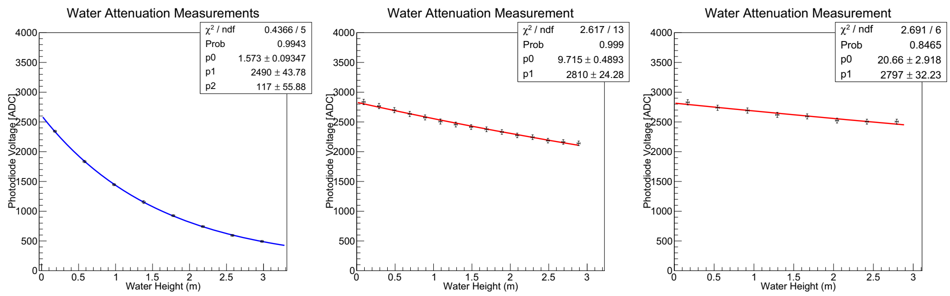


Figure 2. Above: plot showing water attenuation measurement for raw pit water (left); after filtering for 12 days (middle) and after filtering for 25 days (right)

attenuation length of the Wentworth pit water, made using a Secchi disk in daylight, is in the region of 2.5±0.5 m.

2. Experimental Setup

Pit water contained in a 50 gallon barrel is continually passed through the cleaning system comprised of a UV sterilizer, a 1 μm carbon filter, and a 0.2 μm generic filter at a rate of 0.06 litres per minute (lpm) and circulated back into the barrel. The rate is set to simulate the rate of turnover in a large 30m diameter CHIPS detector of 490 lpm for each 2m high detector slice. This leads to a full water exchange every three weeks approximately[1]. The fully automated measuring apparatus was controlled by a BeagleBone Black (BBB) Linux RISC machine. The setup is shown in Figure 1. A vertically mounted cylindrical tube of 3.2 m length and 2 inch diameter schedule 80 PVC pipe was sealed with a transparent perspex plate at the bottom through which a single 0.25" water pipe was inserted. This set up was inspired by the measuring equipment at University of California, Irvine[2].

The column was filled via a servo operating a valve and controlled by the BBB to direct the water away from the filters and into the tube. The pump was allowed to run until the column contained a total water height of 3m, and was then stopped via a relay. A Thorlabs CPS405 collimated laser diode was mounted on a kinematic stage and was positioned to shine vertically upwards along the axis of the column. A lens with a focal length of 50 mm was inserted at the top of the column, 50 mm below a blue sensitive photodiode (1125-1009-ND 525NM) on axis at the top of the tube looking down at the laser. The photodiode output was amplified using a transimpedance amplifier.

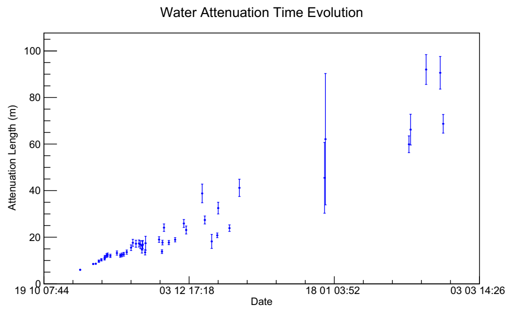
3. Data Analysis

The attenuation length λ is given by

$$\mathrm{I} = \mathrm{I_0} e^{-x/\lambda} \tag{1}$$

where $\mathrm{I_0}$ is the light intensity with no water in the column and x is the water height. The accuracy of the measurement is limited by the length of the column, the stability of the laser and the photo diode, the stability of the ambient temperature and the amplifier circuit noise. There is therefore a limit to the maximum attenuation length measurement achievable. The maximum voltage that can be digitized by the ADC is 1.6V, and this corresponds to 4192 ADC counts. For maximum sensitivity, the empty measurement will correspond to about 4000 ADC counts, meaning that a single ADC count difference corresponds to 0.025%. The longer the

Figure 3. Plot showing how attenuation length improved with time while the water was continuously circulated through the filtration system.



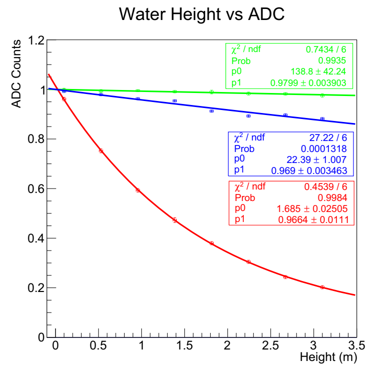


Figure 4. Attenuation length measurements at the start (red), after 1.5 h(blue) and after 12 h(green). The y axes have been normalised to take out long term drift.

column, the more sensitive the measurement can be as it will increase the difference between the empty and full light level.

4. Results

Initial measurements of the unfiltered pit water can be seen in Figure 2, where the attenuation length was measured to be 1.6 ± 0.05m. The result is in reasonable agreement with the measurement with the Secchi disk for white light.

Once the filtration had commenced, samples were taken regularly from the barrel to observe how the attenuation length increased with time. The results of these measurements can be seen in Figure 3 at the start (left), after 12 days (middle) and after 25 days(right).

It can be seen that the filtration system is effective with a clearly increasing trend in attenuation length over the first 60 days. There were no measurements available in February but measurements resumed in March. The trend indicates that the water was being cleaned to the point of reaching values of greater than 50m after 3-4 months. This suggests a relatively simple filtration system will be adequate for a detector size of 30m diameter.

Once the time constant of the water cleaning had been determined, the stability of the setup was improved by increasing the water recirculation speed to clean the water much faster. Figure 4 shows three such measurements taken at intervals of 0, 1.5 and 12 hours of water circulation with attenuation lengths of λ=1.68±0.02ṁ, 22.4±1.2ṁ and 139±42ṁ respectively.

5. Conclusions

The attenuation length of the water from the Wentworth Pit 2W, site of the CHIPS experiment, has been measured during filtration. The UV sterilization and simple filtering method was found to deliver in the region of 100 m attention length at a wavelength of 405 nm. This is adequate for a 30m diameter CHIPS detector as shown by detailed simulation and reconstruction studies[3]. Without the need for the exclusion of dissolved solids, the density difference between inside and outside the detector is small. This is good news for the light-weight structure design.

References

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