Updates on the Lake Design for SWGO

Hazal Goksu\textsuperscript{a,*} for the SWGO collaboration

\textsuperscript{a}Max Planck Institut fur Kernphysik (MPIK),
Saupfercheckweg 1, Heidelberg, Germany

E-mail: hgoksu@mpi-hd.mpg.de

The lake concept is one of the detector design options considered for the Southern Wide-field Gamma-ray Observatory (SWGO), a next-generation high altitude gamma-ray observatory in the southern hemisphere consisting of an array of water Cherenkov detectors. With its wide energy range, wide field of view, large duty cycle and location it will complement the other existing and planned gamma-ray observatories. In the lake concept, instead of having tanks filled with water, bladders filled with clean water are deployed near the surface of a natural or artificial lake. Each bladder is a light-tight stand-alone unit containing one or more photosensors. The prototyping efforts for the lake concept are in an advanced stage with multiple options and factors, such as the impact of chosen materials on water quality, being considered. In this contribution, we will give an update on the planning and prototyping studies for this detector design option.
1. Introduction

The Southern Wide-field Gamma-ray Observatory (SWGO) is a next generation ground particle array that will be built in the Southern hemisphere. Similar to other similar ground particle gamma-ray observatories such as High-Altitude Water Cherenkov Observatory (HAWC) [1] and Large High Altitude Air Shower Observatory (LHAASO) [2], it will be an array of water Cherenkov detectors. The individual water Cherenkov detector units of SWGO may consist of rotomolded or steel tanks or bladders floating in a body of water [5]. The lake concept is a possible unit detector design that is considered by SWGO, where light-tight stand-alone units containing one or more photosensors, namely bladders, filled with clean water are deployed near the surface of a natural or artificial lake. As outlined in a previous proceedings contribution [6], the lake design presents the advantage of an anticipated lower cost and higher flexibility in design, however, it also brings about a restriction of choice in sites and more requirements on bladders.

2. Detector Unit Design

The unit detectors in the lake design are separate stand-alone bladders that are kept in position with floaters. The bladders do not need support from any tank structure as they would be inside a large body of water.

The unit detector bladder is a circular structure with a photomultiplier tube (PMT) with a PVC support hanging from a hatch at the top side of the bladder. It is held in position with floaters, circular pipes filled with air that are connected to the bladder.

The bladder materials are required to have mechanical strength and durability, withstand increased UV radiation at high altitudes, be light tight and are needed to not contaminate the purified water they are filled with. If the bladders are to be placed in a natural lake, depending on the size of the lake the tensile strength requirements to withstand water motion becomes even more crucial. If instead an artificial lake is built to insert bladders, wave motion can be minimized. HDPE materials are seen to be ideal for this purpose, in light of our water contamination and light tightness tests. In order to fulfill these requirements, custom-made films with several layers would be used to manufacture bladders, this is similar to the approach of HAWC, LHAASO and the Pierre Auger Observatory [11] bladders.

The bladders are also expected to be double-chamber units, where the upper volume is for electromagnetic detection and the lower volume is for helping with muon identification. In the double-chamber designs, a single PMT support structure houses a PMT facing upward for the electromagnetic chamber, and a second PMT facing downward for the muon chamber. Optimization studies regarding the aspect ratio of these optically separate volumes [7] show that a ratio of 2.5 to 0.5 would optimize the cost and signal. The optimal height of these volumes also depends on their diameter. This study and other simulations show that having the lower layer coated with a reflective material would maximize its signal efficiency while worsening the timing. This trade-off is optimized with an upper chamber that has a partially reflective coating, and a lower chamber that is completely reflective.

There are different design options being considered for the reflective-material-coated lower chamber, shown in Figure 1. The first option is to have a bladder with a membrane in the middle,
Figure 1: The options for the lower chamber. A. Double-layered bladder with a membrane. B. Two separate bladders are connected in the middle. C. A Tyvek-only bladder immersed in a bigger bladder.

The second option is to have two different bladders that are connected, and the third option is to have a bladder within the bladder approach. For the first two options, the reflective material needs to be connected directly to the outer bladder material. Although options such as spot gluing were tried out, the best option for large-scale production would be to laminate reflective material to the bladder material directly and produce the bladder afterward. The last option, bladder within bladder, or ‘muon matryoshka’, eliminates the need to connect the reflective liner to the outer bladder altogether. In this option, a bladder is made only using the reflective liner and is inserted along with the double-PMT setup inside the bladder.

Figure 2: Lake Simulation Tank Left: The Lake simulation tank at MPIK has a 10-meter diameter and is 7 meters in height. It contains two prototype bladders Right: Sketch of the one-chamber PVC bladder inside lake simulation tank, along with two muon taggers. This setup was used to perform three-fold coincidence measurements.

3. Single Chamber Tests

Prior to double-layer tests, prototyping tests with bladders consisting of a single chamber were carried out. As was explained in the previous proceedings contribution [6], there is a lake simulation
tank in our institute, seen in Figure 2. In order to make initial tests, we used two muon taggers to tag muons that passed through the entire water simulation tank, by inserting one at the bottom of our tank, one at the top, and putting our bladder of interest in the middle of these taggers. Each of the muon taggers consists of an 8-inch Hamamatsu R5912 PMT inside a commercial black barrel of 41 cm diameter and 75 cm length, lined with reflective material (Tyvek 1082D) and filled with clean water. We use two muon taggers to have well-defined particle trajectories, enabling us to make three-fold coincidence measurements.

Our first realistic-scale bladder was made up of PVC material, with one chamber and a single PMT inserted inside. The bladder has a hatch at the top, with the single PMT hanging via three ropes from the hatch as shown in the sketch in Figure 2.

Detector signals from the bladders and taggers inside the lake simulation tank are routed to a cabin next to the tank that is equipped with the FlashCam Data Acquisition (DAQ) system [8], which, throughout our studies, had a readout window of 128 samples and takes one sample every 4 nanoseconds, giving a total of 512 ns readout.

![Figure 3: The time signal of the three-fold coincidence runs taken with the one-chamber PVC bladder. "Bottom" and "top" denote the bottom and top muon taggers. The 4 ns time difference between the two lines is within the precision of the ADC. The offset in the axis is due to the differences in cable length.](image)

the plots in Figure 3 show our first three-fold coincidence measurements, using the two muon taggers and the bladder. For these measurements, a threshold of 20 LSB and a trigger condition of 100 ns between the top and bottom taggers was used. The correlation between the bladder and top & bottom muon taggers is seen in these plots, where the time difference is due to cable length differences. The measured coincidence rate is $\approx 0.017$, which is consistent with simulations done using HAWCSim, a package based on GEANT4 [9] with water absorption lengths less than 1 m. Rates ranging from $0.010$ to $0.05$ were seen in these simulations.

These measurements were done with the PVC bladder, which was shown to degrade water quality significantly through our water absorption studies. Furthermore, the PVC bladder has a single chamber. Our next step would be to perform four-fold coincidence measurements using the two muon taggers and a bladder made from a more realistic material that has two chambers.

### 4. First Double Chamber Concept

Different double chamber concepts are being considered as shown in Figure 1. Options A and B most likely require the lamination of reflective materials (Tyvek) onto the outer bladder material, which should be done before the bladders are manufactured. On the other hand, option C
is an approach we are able to use without waiting to produce our custom Tyvek-laminated bladder materials. Since we do not have such materials available to us at the moment, in order to be able to carry out double-chamber prototyping tests with our lake simulation tank, we are working on building an option C prototype in our facility in Heidelberg. We have already built the first 'matryoshka' prototype at the time of writing.

The first prototype for the lower chamber is made in the shape of an octagon that is held via a spider/umbrella structure made up of eight PVC pipes. The chamber is entirely made up of Tyvek 1082D and is spot-attached with a custom impulse heat sealer.

The umbrella mechanism is designed such that in its closed position the muon matryoshka is able to go through the hatch of a one-chamber bladder, and then once it is through the hatch, the umbrella structure can be opened via ropes.

Currently, we are carrying out mechanical tests to see the feasibility of this approach, as shown in Figure 4. After testing a 70 cm long diagonal prototype with four umbrella arms inside and outside water, we have built our very first full-scale prototype, with a 3 m long diagonal. We are in the process of testing this mechanism inside water. The 'muon matryoshka' could provide us with a quick way to make four-fold coincidence tests in our lake simulation tank and could also be a plausible option for the final array (including tank options).

5. Outlook

SWGO will be the first ground-particle gamma-ray observatory in the Southern Hemisphere and is expected to complement the existing ones in the North. The lake design is a promising unit.
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detector design idea that is expected to be cost-effective.
The prototyping work done for the lake design is in close contact with any other alternative unit
detector design that requires bladders that are in contact with purified water. Any bladder designed
for the lake concept could also be used inside tanks. Moreover, the lake design is flexible in that it
can be used inside suitable natural lakes as well as artificial ponds.

References

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[8] F. Werner et al., Performance Verification of the FlashCam Prototype Camera for the

Full Authors List: SWGO Collaboration

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