Light concentrators for large-volume detector at the Baksan Neutrino Observatory

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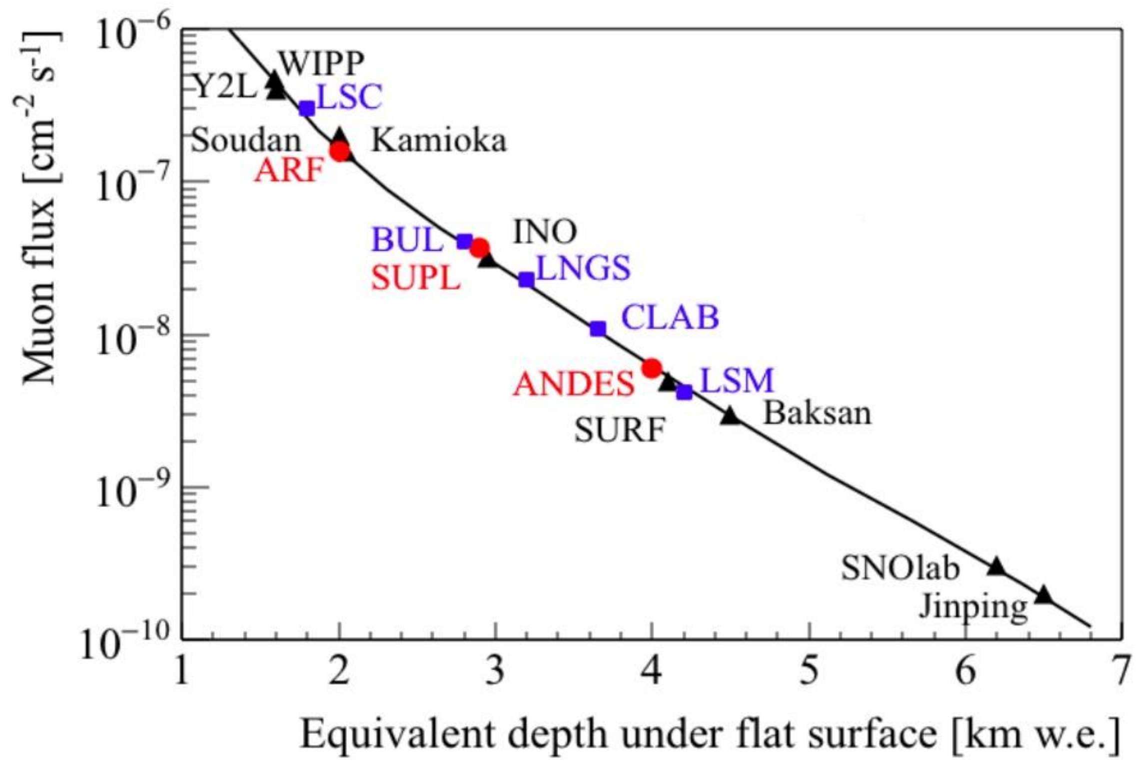
Motivation

A new large-volume Baksan neutrino telescope (10 kt liquid scintillator) will be created at the Baksan Neutrino Observatory of the Institute for Nuclear Research Russian Academy of Sciences at a depth of about 4700 mwe (meter water equivalent) [1],[2]. The main physics goals of the detector are low-energy neutrino physics, geophysics and astrophysics. The highest possible light yield is crucial for detector development. Mounting light concentrators to photomultiplier tubes (PMTs) is one of the ways to increase light collection efficiency. Such device takes light incident on an entrance aperture over a given angular range and reflects by a curved surface to a smaller exit aperture of the PMT photocathode. Additionally, concentrators can reduce total experiment costs by minimizing the required number of PMTs. Light concentrators based on Winston cone [3] was successfully used by several neutrino experiments, for example, the SNO [4] and Borexino [5]and cosmic ray telescopes. We present the results of recent R&D work aimed to develop light concentrators for the Baksan large-volume liquid scintillation neutrino detector.

Location

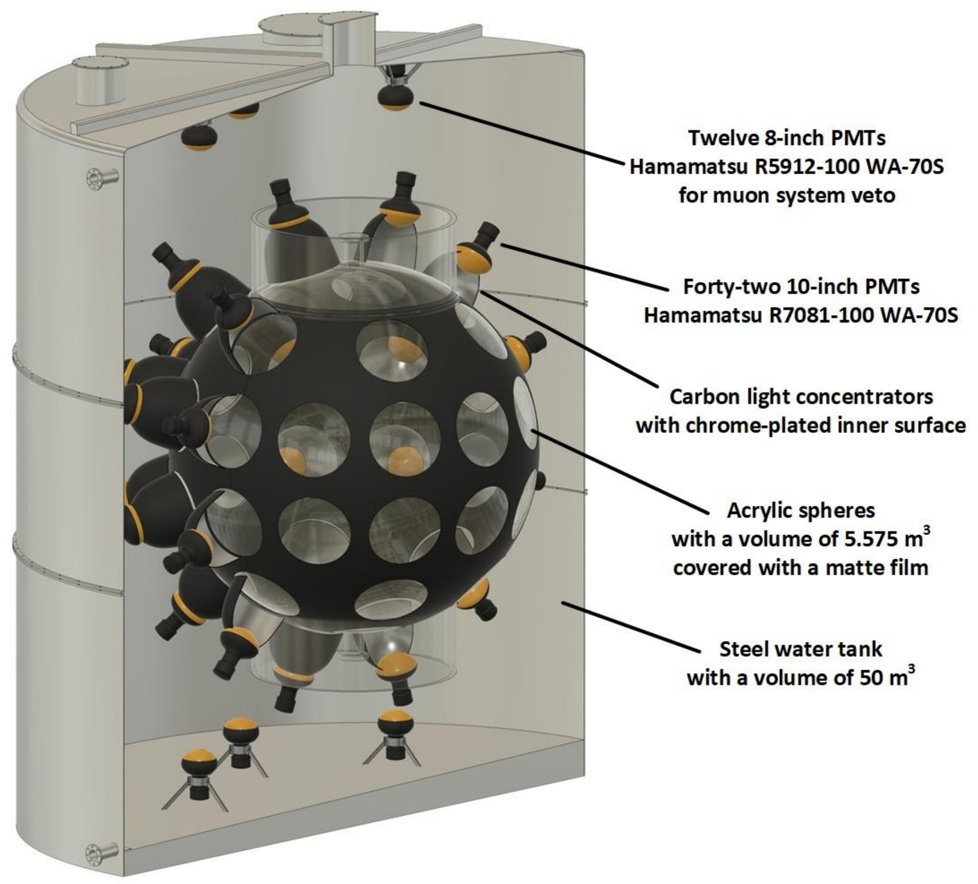
Baksan Neutrino Observatory of INR RAS is located in vicinity of mountain Elbrus, in the Baksan valley of Kabardino-Balkaria (Russia). BNO has several underground facilities. The overburden of underground laboratories reaches 4700 mwe.



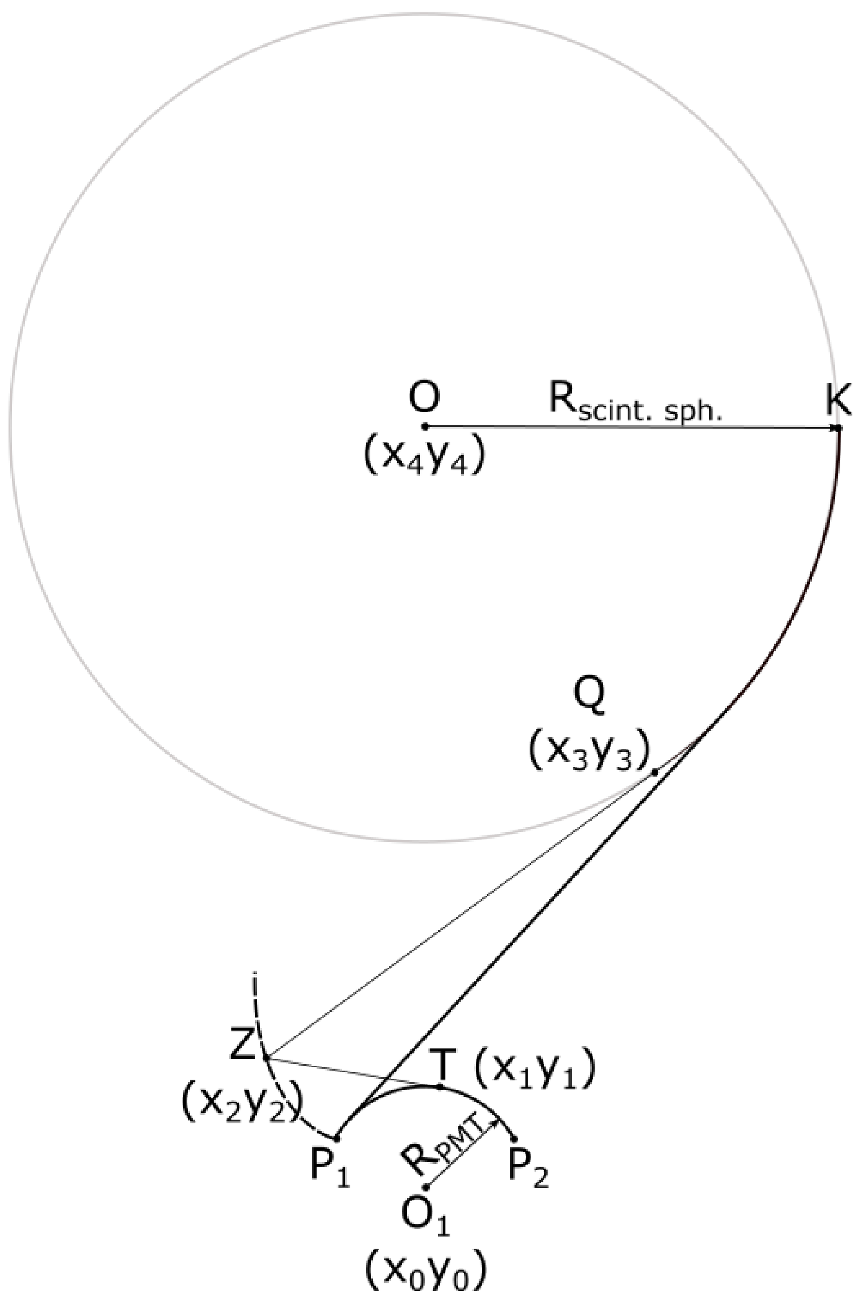
5t prototype design

The neutrino telescope project is divided into four stages with increasing detection mass of liquid scintillator target: from 0.5t prototype to 5t (second prototype), 100t (third stage) and thefull-scale detector (10kt) on the last phase. The first and the second prototypes have a two-zone design. Currently, the first stage of the project is completed, the second prototype (5t) is under construction.

Figure on the left shows 5t detector prototype design. The central zone is an acrylic sphere filled with an ultrapure liquid scintillator (linear alkylbenzene (LAB) + PPO) and surrounded by a second zone. The second zone is filled with water to protect against external radioactivity and also serves as muon veto. The scintillator sphere is surrounded by 42 10-inch Hamamatsu R7081-100 PMTs(220 mm. diameter photocathode). On the second prototype, we decided to use light concentrators to increase total light yield.



Concentrator design method



The concentrator was designed using the String method (also known as Winston cone method[3]) which considers the shape of the photocathode. Figure 2 gives the illustration of concentrator cone shape design based on the String method.

Between scintillation sphere with the centre at point O and PMT photocathode with curvature centre O_1, let's stretch the "string". One end of the "string" is tied on point K, another end on point P_2 which is the right boundary of the photocathode surface. We choose the length of the "string" so that, when taut, it wraps around the photocathode and reaches point P_1 (the left border of the photocathode). Put the tip of a pencil at point P_1. Holding the length fixed, we trace out the concentrator profile as the tip moves from P_1 to the top.

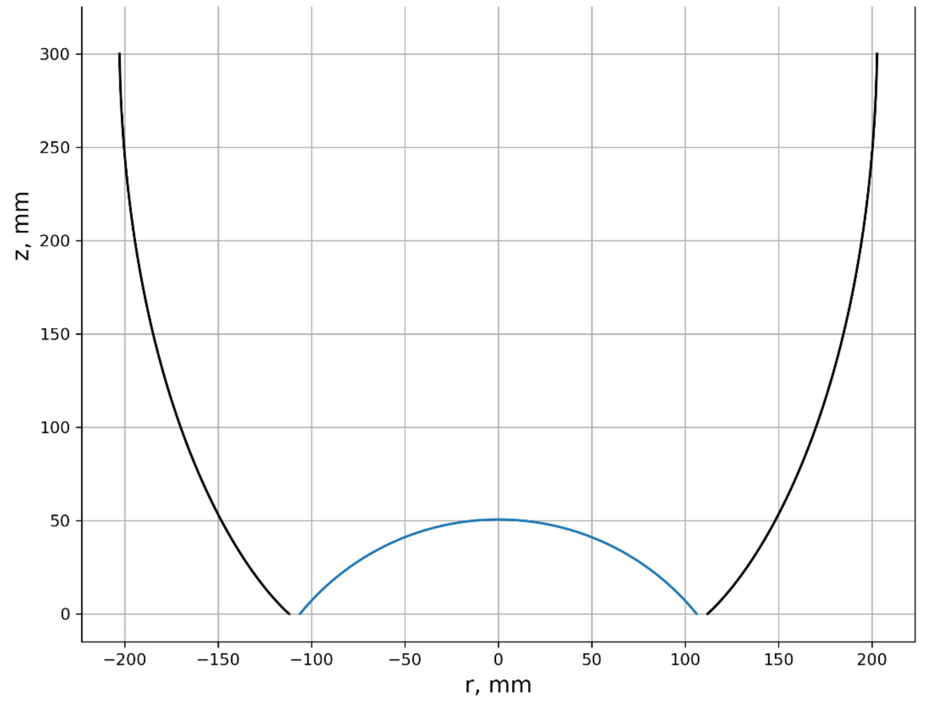
Rotating the profile about the axis of symmetry gives the concentrator shape. In 2D case, any incident rays with $\theta < \theta_{cut-off}$ will be reflected onto the photocathode. For 3D case, the light collection efficiency will reduce because in the case of skew incident rays the arch of the photocathode will be lower than at the 2D profile.

Implementation of the string method was done by using python3 programming language with NumPy library.

Results

The calculated concentrator shape is presented in the figure below. The diameter of the exit aperture (224 mm.) is a little bit more than the diameter of the PMT photocathode due to construction reasons. Because of the limited size of the water tank and supporting grid constraints, the total length of the cone is bounded by 300 mm.

The cone shape is optimized for this length and given exit aperture size. The entrance aperture diameter is 405 mm. The concentrator increase light yield nearly 3 times compared to bare PMT and $\theta_{cut-off} \approx 50^{\circ}$.



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Acknowledgments

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