

Design of the LHAASO-KM2A μ Detector prototypes

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Abstract: Large High Altitude Air Shower Observatory (LHAASO) will be promoted at YBJ. As a main detectors array in LHAASO, one square kilometer EAS array (KM2A) consists of 5137 electromagnetic charge detectors (EDs) and 1209 muon detectors (MDs). Two MD prototypes have been built in Tibet. In this talk the technique of the prototypes will be presented. The prototypes consist of concrete tank and a liner made of 3 layers. Some preliminary results have been achieved from the simulation of the prototypes.

Keywords: Muon Detector, Simulation and Optimization, Prototype

1 Introduction

The large high altitude air shower observatory (LHAASO) [1] project is proposed to search for cosmic ray sources by using gamma rays up to 1 PeV, to survey the whole northern sky for gamma ray sources above 100 GeV, and to study cosmic ray physics from 5 TeV to 1 EeV in energy spectrum for individual composition, etc.

The LHAASO detector array was built at Yangbajing (YBJ) valley of Tibet at the high altitude of 4300 m. As a main detectors array, one square kilometer extensive air showers (EAS) array (KM2A) consists of 5137 electromagnetic particle detectors (EDs, 15 m spacing) and 1209 muon detectors (MDs, 30 m spacing) distributed within the region with a radius of 560 m.

In this paper, the optimization design and performance of MD are presented, as well as the relevant simulation. It describes the liners, accessories, and relevant steps for assembly, as well as an experimental setup.

2 Design

MDs are designed to realize a strong background excluding ability for detectors and to greatly improve the array detection sensitivity, so as to effectively determine the primary particle species. As air shower contains a lot of electromagnetic compositions, the number of which is 1-2 magnitudes more than muons, so as to accurately detect the muon density. An electromagnetic absorption

layer of certain thickness above the probe of the detector is utilized, and for muon's strong penetrating ability to go through absorbing layer, the probe gives signal due to muons' traveling and acting in the water volume, leaving the electromagnetic compositions in the absorber. Water Cherenkov detector is chosen considering its robustness and low cost [2], and another reason is that the relative amount of energy converted into Cherenkov light strongly depends on the particle type. For instance, electron energy rapidly dissipates through bremsstrahlung inside the tank [4], but comparatively, muons can give a higher signal density. Therefore, it is one of the significant reasons to choose water Cherenkov detector for the muon detector array layout.

Comprehensive consideration of the actual geological condition and detector cost in YBJ, above the muon detector experiment using dirt as absorbing layer can effectively shield against the electromagnetic compositions of air shower. Each of the muon detector includes a 6.8 m diameter concrete tank containing a sealed liner with a reflective inner surface, and the liner contains 44 t of pure water. Cherenkov light produced by the passage of particles through the water is collected by one eight-inch-diameter PMT which is in the top center of the tank and looks downwards through the window of optical PMMA plastic into the water. The general components of the muon detector station are shown in Fig. 1.

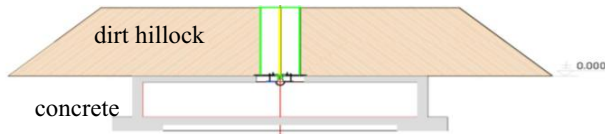


Fig.1. schematic view of μ detector

3 Simulation

We simulate and optimize the muon detector structure [3], so as to determine the detector parameters, such as the height of tank, the height of dirt above the MDs and so on for the design of prototype.

The muon detector simulation is based on the well established Geant 4 package. A dedicated module, called G4Fast, has been implemented to reduce the computing time. This module produces Cherenkov photons along the path of the injected particle and tracks them through the water until they are absorbed or they reach the active photocathode area of a PMT. According to the real instances into detector, when the thickness of dirt layer varies, photomultiplier tubes get photon numbers and the result is shown in Fig.2. The left is a muon incidence and the right is a γ incidence. The number of photoelectrons of γ incident significantly reduces with the increase of absorbing layer thickness, and when it reaches 2m, the number of photoelectrons is basically zero. A gaussian fit is made according to the photoelectrons number, and the detect efficiency is in chart.1. When absorbing layer thickness reaches 2.5m, muon detect efficiency is almost 80%, and γ is only seven of a million. Thus, we conclude that absorbing layer thickness of 2.5m is more reasonable, which can reduce the influence of punching-through effect.

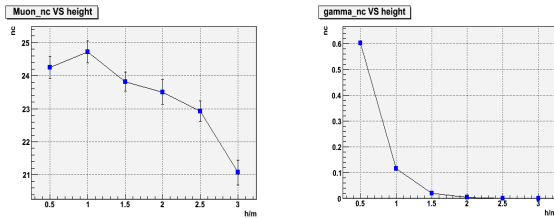


Fig.4 photoelectrons number versus the thickness of dirt layer

Chart.1. Punching-through effect

Dirt high	Muon MPV	Detect efficiency (0.5MPV)	Gama	Punching through (0.5MPV)
0.5m	19.07	84.02%	0.6028	1.4584%
1.0m	19.12	85.44%	0.1164	0.2303%
1.5m	18.96	84.96%	0.02031	0.0291%

2.0m	18.72	83.62%	0.003421	0.0025%
2.5m	18.69	82.04%	0.000656	0.0007%
3.0m	18.59	75.20%	8e-5	0.0001%

Figure 3 shows some results of this study. Now the lining reflectivity is 97.5%. As the water depth increases from zero, the number of photoelectrons yield initially rises; this is a result of the increasing muon track length, and hence larger Cherenkov burst released. However, there are two effects, which combine to counteract this rise: first, the increasing depth results in decreasing photocathode area when expressed as a fraction of total tank wall area; second, the mean photon path length required to reach a photomultiplier also grows. For a cylindrical tank of radius 3.4 m, the photoelectrons yield is predicted to the peak at a depth close to 1.2 m. At the same time, as the reflectivity and water absorption length increase, photoelectrons yield rises. So the validity of this statement is dependent on the assumed lining material reflectivity and water absorption length values.

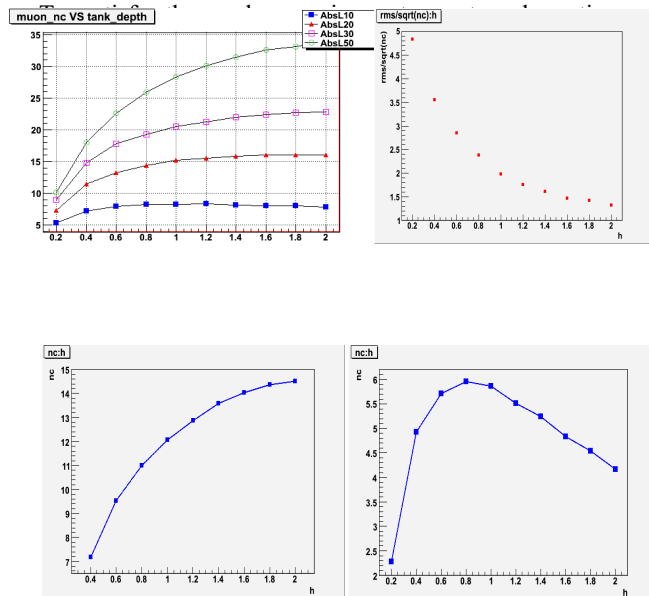


Fig.3. water tank depth studies via simulation .At top left the mean photoelectrons yield as a function of tank depth for muons' penetrating vertically is shown. At top right a measure of the non-proportionality of the detector is plotted. Along the bottom, the left is muon-photoelectron yield distributions, but the reflectivity is 90%, and the right is γ - photoelectron yield distributions.

4 Tank liners

4.1 Development and design

Tank liners are right circular cylinders made of a flexible plastic material, conforming to the inside surface of the out concrete tanks, covered by a dirt hillock of 2.5m thickness, which can effectively shield against the electromagnetic compositions of air shower such as e^+ , e^- and γ -ray. The liners have a diameter of 6.8 m and a height of 1.2 m, fulfilling three functions: they enclose

the water volume, prevent chemical contamination, active microbe, and the loss of water, and provide a barrier against any external light that enters the tank water volume; they are used to diffusively reflect Cherenkov light produced by entering μ shower articles when traversing the water; [2] and they provide optical access to the water volume for the PMTs in position collecting the Cherenkov light.

On the top of the liner, there are one window and two fill ports with screw caps hermetically sealed to it. The window is a transmission cover made of PMMA, a kind of optical plastic, which allows the mounting of the PMT. The fill ports are used to fill and vent the tank.

In the design process, five targets are taken into consideration [2], which are the strength, opacity to external light, strong diffuse reflectivity of inner surface for the Cherenkov light, good sealability, excellent chemical resistance, and prevention against contamination of water volume by minimal extractable matter from the materials and microbe.

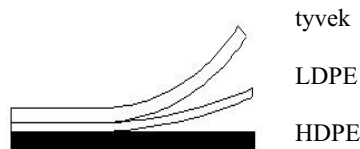


Fig.4. The drawing of composite construction of the laminate

The liners are made of separate laminates by proper processing method, and the laminates are composed of three-layer co-extruded materials (see Fig.4), the inner is Tyvek[®] 1082D made by Dupont[®], which is an opaque material and is chosen as the inner reflective layer for its excellent strength, flexibility and diffuse reflectivity for near ultraviolet light. It is a high density polyethylene non-woven material, which minimizes the chemicals available to leach into the water volume. The middle layer is LDPE film, and the out layer is black HDPE film of 1.0 mm thickness, which could prevent external light to a level of single photons from entering the water volume, and the HDPE film is also chosen as the liner material for its good strength, outstanding chemical resistance and minimal extractable matter, which might permeate and contaminate the water volume comparing with similar materials with above characteristics.

4.2 Assembly method

Liner is assembled by firstly processing three laminates of three-layer co-extruded materials which are Tyvek, LDPE and HDPE film respectively from inside to outside, and then welding them together by plastic welding rods which are polyethylene material. The three laminates are the cylinder top, bottom and profile respectively. For the design, in the top laminate, there will be four holes opened in fixed sizes respectively and then one window and two ports with screw caps will be hermetically sealed to them, and the window made of PMMA material is used in mounting the PMT and to protect the face of it when working under water surface,

the ports for filling and venting. In order to check the assembly method and to carry out a related experiment for the performances, we have made a small prototype in the met



Fig.5. The liner prototype without the assembling of PMT enclosures, its diameter is 0.58 m, and height is 0.92 m.

4.3 PMT enclosure and assembly

The PMT enclosures are designed to allow the PMT to collect Cherenkov light from the water volume, to protect the PMT face which is fragile, to provide with a cover to shield the PMT from external light, and to construct a PE plastic enterclose called hatchway, by which the PMT could be mounted commodiously through the upper dirt hillock

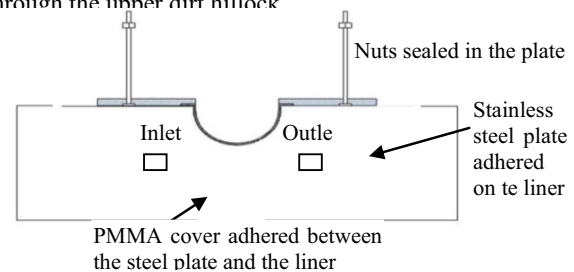


Fig.6. The section view of the assembling of PMMA cover and stainless steel plate flange with inlet, outlet ports in it and nuts sealed in it.

The window made of PMMA plastic, which is formed fitting approximately the nominal PMT face, is heat-sealed to a hole in the top laminate of the liner. Above the PMMA window, there is an annular stainless steel plate flange with nuts sealed in it which is adhered to the liner (see Fig.6). The flange is used to support the liner top to maintain the liner's normal cylindrical shape when the liner installed into the concrete tank is filled with pure water. The space between the window and the PMT face is filled with the silicone oil [2] for optically coupled. Other enclosures are then assembled (see Fig.7), containing plastic hatchway, hatch cover and a process plastic pipe for installing the PMT. The hatchway is like a chimney through the upper dirt hillock and the top of it is sealed with the hatch cover. The PMT could be protected by these enclosures from external light and possible damage caused by surrounding medium.

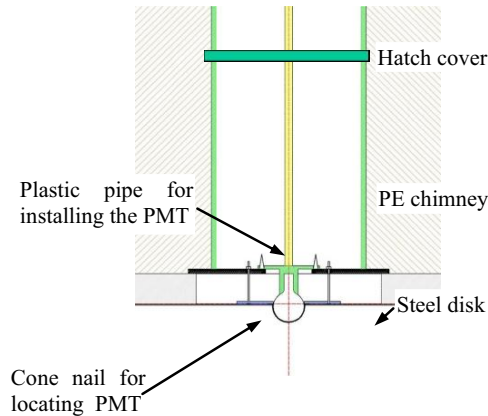


Fig.7. The cutaway view of assembling of the PMT enclosures containing hatch cover, PE chimney, plastic pipe for installing the PMT, and etc..

5 Long Term Stability of the quality of the water

For the KM2A muon detector performance, two prototypes were successively manufactured of different materials and in different methods. The early one is made of 2 layers, and the inner is tyvek and the outer layer is TPU. The later one is made of 3 layer materials described above.

The former is a cylinder with diameter of 0.72m filled with commercially purified water up to a height of 1.2 m. It has a single 8 inch PMT(Hamamasu R5912), located at the center of the tank to collect the Cherenkov light produced by relativistic charged particles in the water volume. The photo-cathode window of the PMT is located at the water surface and looking downwards. In Figure 8, an experimental setup is used to collect the Cherenkov signal due to muons passing through. Muons were selected with a trigger given by the coincidence of signals from two scintillation detectors, with one placed above and the other below the tank. We used an oscillograph to obtain the amplitudes, width and delay time of the PMT pulses.

The fall time of the muon pulses is determined by the water quality and the reflectivity of the Tyvek liner, since Cherenkov emission is a very fast process. This quantity is a measure of the average path length of the photons in the tank before they reach a PMT, and this path length is affected by the attenuation in water as well as the losses at each reflection from the liner. The reflectivity of Tyvek is about 92%. Suppose the reflectivity of Tyvek is

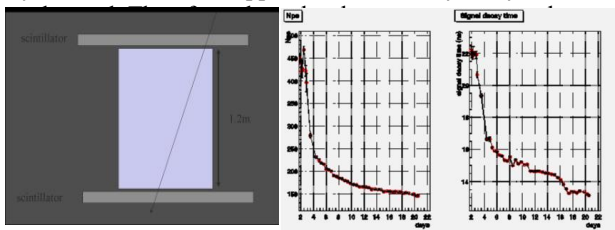


Fig.8. Muon detector prototype performance. The experimental set-up(left), the pulse decay (right) with vertical axis npe and the horizontal axis time(d).

6 Summary and Conclusions

We have performed a GEANT4 based simulation of the muon detector for an optimal design by simulating the response of a detector to muons and soft electromagnetic (EM) components under a variety of detector parameters, such as water depth, tyvek reflectivity and water absorption length etc.. According to the simulation and considering the factors including detection efficiency, construction cost and μ /EM distinguish power etc, the detector parameters are determined, with the height of tank 1.2 m and the thickness of Dirt 2.5 m. The primary structure is designed under the simulation results. The simulation results show that the absorption length is one of the significant parameters of the detector performances. In order to achieve the detection target, it is demanded that the water absorption length be 30 m at least, thus the quite high quality standard is demanded for the water of the detectors. And to maintain the long-term stability of the water quality, more surveys would be carried out.

Acknowledgments

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References

- [1] Z. Cao et al., LHAASO Collaboration, in: Proceedings of 31st ICRC, 2009.
- [2] I. Allekotte et al., Nuclear Instruments and Methods in Physics Research A 586 (2008) 409 - 420
- [3] X.H. Ma et al., LHAASO Collaboration, in: Proceedings of 31st ICRC, 2009.
- [4] A. Etchegoyen et al., Nuclear Instruments and Methods in Physics Research A 545 (2005) 602 - 612