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A new concept for an active element for the large cosmic ray calorimeter ANI

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Abstract. Abstract. For the ANI calorimeter (40 x 40 m^2, 6 concrete absorber layers of 1 m thickness each) at mount Aragatz, Armenia, a cheap and efficient active detector element is needed. One solution is to use long, square tubes (20 x 0.3 x 0.3 m^3) filled with wavelength shifter dye doped water. Two PMTs at the ends serve to read out the Cherenkov light generated by fast charged particles. For the crucial light transport along the tubes the walls are lined by a new superreflector foil from 3M (dielectric reflector foil with R $>$ 98%). From test measurements, a light attenuation of a factor 10-15 over the full length is expected. Due to the high active material fraction of the calorimeter of nearly 15% a good energy and spatial resolution is expected. Prototype results will be presented.

1 Introduction

One of the main disadvantages of Cosmic Ray (CR)/ Astroparticle physics experiments compared to HEP experiments at accelerators is, besides the unknown initial state conditions, the comparatively very low flux. Many experimental efforts are driven by the need to increase the detector area, respectively volume. Cost is a limiting factor and there is a need to find cheap active elements. A typical example is the need for the active element for the large calorimeter project ANI (Danilova, 1992). ANI is located on the Mount Aragatz and is half completed after the dissolution of the former Soviet Union. Besides an operational scintillator array ANI comprises a 40x40 m^2 concrete absorber of 6 layers of 1 m thickness each, interspersed by 40 cm gaps, and an underground cave with muon chambers and an $\approx$ 3500 m^2 magnetised iron spectrometer for muon studies (not completed). The high altitude of 3200 m asl makes this detector particularly interesting for studies of charged CRs above 10^{14} eV where besides the Kascade array at Karlsruhe no other large experiment is planned.

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2 The basic concept

Here we want to present both a concept and the first results from a reduced size prototype for the active element for such a calorimeter, respectively similar applications. The basic elements are long tubes filled with water and read out by 2 photomultipliers (PMT) at both ends. A typical configuration would consists of 20(40) m long tubes of, say, 30 cm diameter, arranged alternatively in x and y direction in consecutive gaps. The inner surface of the tubes are lined with a new highly reflective (specular reflector) foil ensuring good light piping over large distances, respectively of detectors with large aspect ratios (length/diameter). Fast charged particles produce Cherenkov light. A significant fraction of the light ($\approx$ 50%) is absorbed by a dissolved wavelength shifter dye (WLS) and re-emitted around 420-500 nm. The re-emitted light is isotropic and well matched to the high reflectivity of the liner and the sensitivity of standard PMTs. Fig 1 shows the conceptual design of one tube. The main problem in past approaches of similar configuration was the inefficient light transport over long distances. Efficient light transport can only be achieved by specular reflectance materials of high reflectivity. When using aluminised Mylar with about 90% reflectivity the losses are to high after about 20-30 reflections, besides the reflector degradation when in prolonged contact with water. Using the principle of lightguiding in water by a tube of lower refractive index material is excluded by the lack of material. Plexiglas tubes are costly and show long-term degradation because of surface longterm attachment and microcracking. In addition, the achievable numerical aperture with water would restrict light transport to only a small fraction. Highly reflective diffuse materials such as Teflon foils or TYVEK are completely useless as they 'trap' the light quite locally (see fig. 2). The solution is to use the new 3M VM2000 dielectric reflector foil (Weller, 2000) with $>$ 98 % reflectivity between 400 and 700 nm (We are actually negotiating with 3M about extending the high reflectivity down to 300 nm.). The foil does not contain any metal and is completely inert against many liquids and solutions

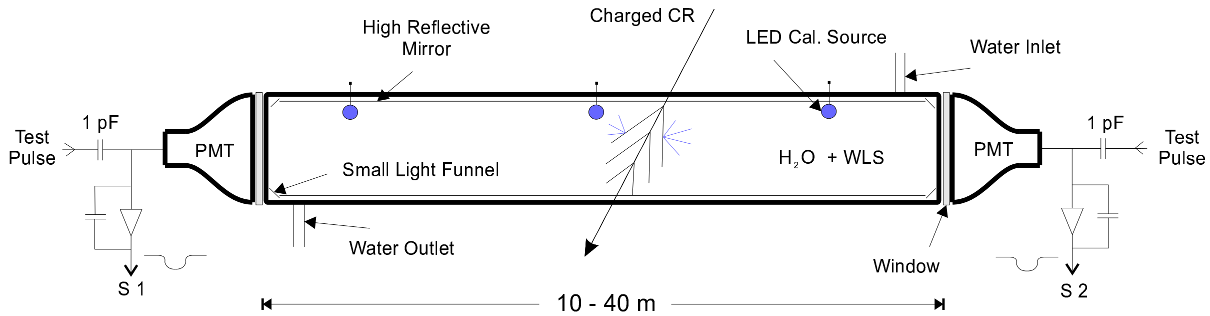

Fig. 1. Conceptual design of a tube with readout.

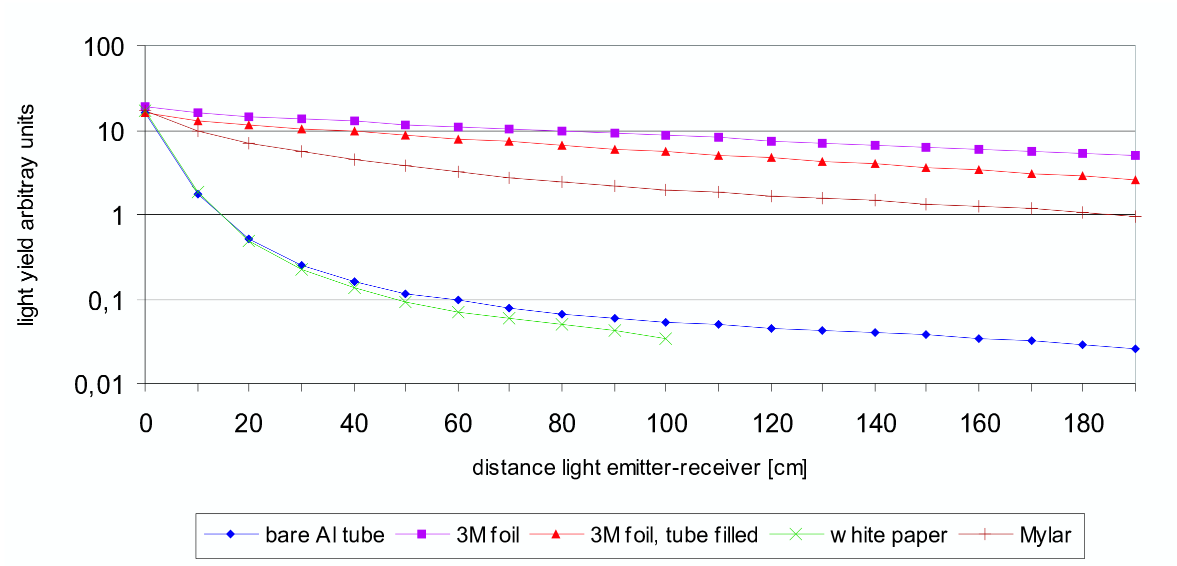

Fig. 2. Signal reduction along a tube of aspect ratio 71 for isotropic emitted light and different lining.

(for example salt dissolved in water or alcohol-water mixtures). Fig 2 shows some light piping studies in a high aspect ration tube lined with different reflectors.As readout elements PMTs with a sensitive area of typically half the end area of the tube are used. Using short Winston type light concentrators of the same 3M foil one can economise on the size of the PMTs and also improve on the time spread by rejecting large angle photon paths at the expense of some signal loss.

Relatively cheap PMTs can be used. As considerable time dispersion of the photon flux develops along the tube one is limited in rate which is nevertheless still many orders of magnitude above the CR flux. For good signal processing the PMT signal has to be integrated. In our tests, we used charge sensitive preamps and shaping amps ($\tau \approx 50$ nsec) developed for the photodiode readout of crystal γ calorimeters. The use of such secondary amplification allows for a few stage PMT operating at medium high voltage and large dynamic range (>80 dB) without PMT saturation effects. The final signal processing and trigger generation is not subject of this paper; as it follows standard methods, no further information will be given.

As tubes commercial water tubes made of polyethylene (PVC...) can be used. Using standard end fittings the mounting of the windows, supply lines etc. makes production very simple and cost effective. For optimal performance, it would be better to use a square (rectangular) profile compared to the readily available round one but also square tubes can be found commercially. (There is a small buoyancy problem with the foil that has a slightly lower specific weight than water. This causes more installation problems when lining square tubes). For filling, we used filtered tap water (in case of very long tubes distilled water should be superior). As WLS many fluorescent dyes can be used, for example dyes used for optical brighteners in washing powder, white paper etc. These dyes are non-poisonous, mass produced, dissolve easily in water and have a quantum efficiency (QE) close to 100%. Fig. 3 shows the absorption and emission curve of our tested WLS, the absorption cut-off of water, the reflectivity of the 3M foil VM 2000 and the QE of a standard PMT with

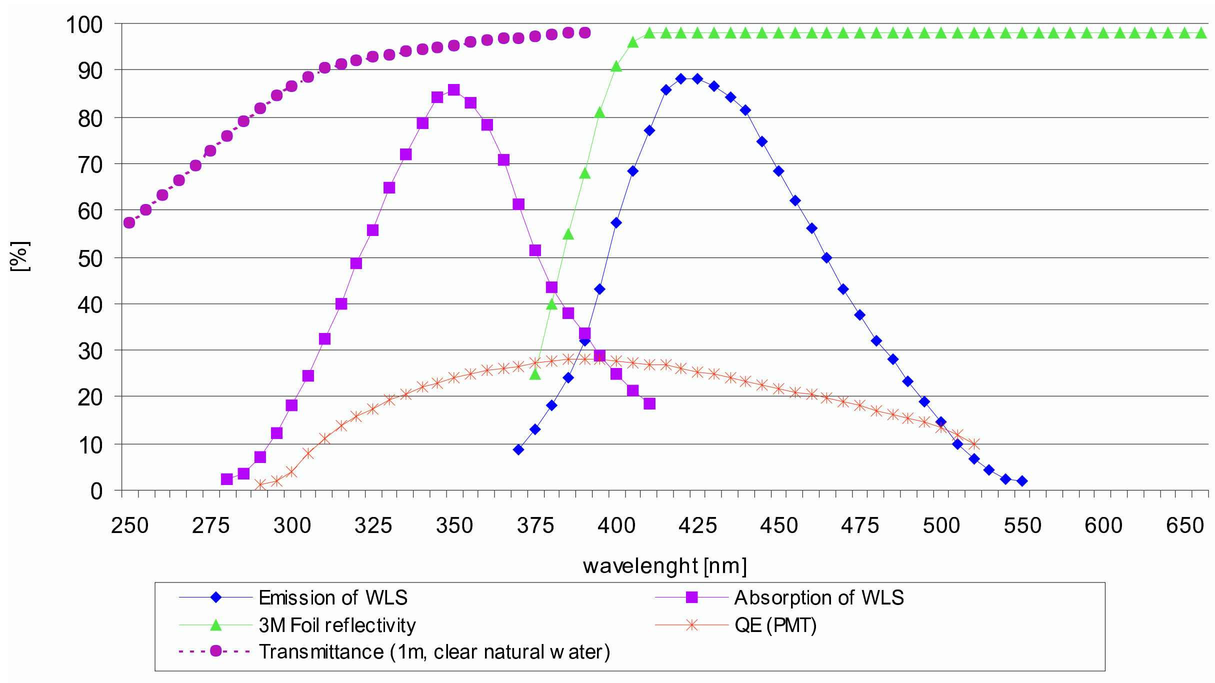

Fig. 3. Some essential optical parameters of the active element.

Bialkali photocathode.

Calibrations and monitoring of the tubes will be performed by i) LED pulsers, ii) by charge pulses injected at the inputs of the charge sensitive preamps and iii) by cosmic muons (2000/sec/20 m tube). LEDs are either blue ones ($< \lambda >$ = 428 nm or $< \lambda >$ = 470 nm) or Nichia UV-LEDs ($< \lambda >$ = 370 nm) exciting the nearby WLS. Some problems might occur during subzero temperatures in winter, requiring either external heating or replacing the water by a water alcohol mixture, respectively the admixture of salt in the water.

3 Expected performance

In the spectral range between 250 and 400 nm a total of 270 photons/cm pathlength are generated by a $\beta \approx$ traversing charged particle. For a WLS (Basacid) of $\approx$ 95% QE and a total pathlength of 30 cm about 2800 photons are generated isotropically, which are emitted basically 1/2:1/2 in the two directions. Due to water absorption and reflectivity losses, about 5% (on average) will reach each PMT. For a typical mean PMT QE of 15% one expects a signal of 20 photoelectrons for the most distant particles, i.e., even the signal of a single muon is visible. If the detector tube is extended to 40 m than the signal from a single muon passing at the far distance is barely visible. In calorimeter applications the expected signal from hadronic components of EAS will be sufficiently large. Coincidence signals from double-sided readout result in a very high signal to noise rejection even in case of muons.

Two-dimensional readout is needed to i) determine the c.o.g. of the shower, ii) solve ambiguities in case of multiple subshowers and iii) correct the signal attenuation along the tube. The shower c.o.g. can be determined by 'current division' or by timing differences. In both cases a resolution of better than 2 m (energy dependent) should be achievable. To fully exploit timing one has to use constant fraction discriminators which would result in a time resolution of $<$ 1/10 of the shaping time, i.e., $<$ 5 nsec. In the case of the ANI calorimeter the fraction of active material is around 0.15, i.e., a relatively good energy resolution is expected although only the shower tail can be sampled. The performance will be quite different if the top layer is located above or below the top concrete plate. ANI is basically a 'tailcatcher' calorimeter and a typical energy resolution of 20% is expected based on HEP data. MC simulations are pending.

A first cost estimate shows that a tube element can be build for $ 1500-2000 (dominated by the PMT price) for both the 20 and 40 m long units. A total of 900 (40 m version) respectively 1800 tubes of 20 m length would be needed for the ANI calorimeter.

References

Danilova T.V. et al., NIM A 323, 104-107, 1992
Weller M.F. et al.; Science Vol. 287, 2451, 2000