High School Students’ Water Cherenkov Detector

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Abstract

During last decade a lot of outreach activities were born to bring Science in the youths' hearts through the study of elementary particles physics using frontier detectors.
The aim of this project, i-SpeChe, is to develop a multipurpose prototype detector for a wide range of experiments from the study of natural radioactivity to cosmic rays flux using a SiPM matrix easily coupled to different scintillators or, to realize a Water Cherenkov Detector, to water tank.

All the detectors used for outreach activities must be robust, easy to use and transport, LV based and economic. The choice is usually scintillator+ SiPM and this limits the knowledge of the wide range of existing detectors used in particles and astroparticle physics. Our effort is to realize a Cherenkov detector coupling water to a SiPM matrix.

Cherenkov detectors are now found in a wide variety of unique applications throughout physics, astrophysics, and biomedicine, with more powerful, and larger devices continuing to be developed and implemented. Particular examples include the many detectors at particle accelerators for hadronic particle identification, the large water Cherenkov detectors used for neutrino detection both for astrophysics and accelerator studies, and the imaging air Cherenkov telescopes used to study very-high-energy γ rays in cosmic radiation.

Most of the experiments based on Cherenkov effect in water use PMT. The use of SiPM coupled with water is still under study and i-SpeChe is the first approach for the realization of an outreach Water Cherenkov detector with SiPM.

Detector design

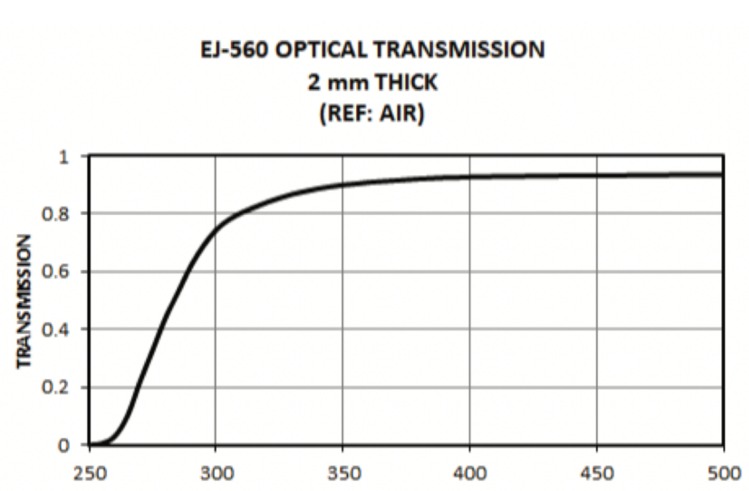
The detector prototype, i-SpeChe, is a modified I-Spector, CAEN, an electronic system based on a SiPM area (24 × 24 mm²) with integrated HV power supply, temperature, voltage and current monitor. All SiPMs of the area are connected in parallel to increase the active area of the matrix.
The i-Spector unit is fully-integrated compact tube based on a SiPM area to provide a full-featured compact photodetection system for spectroscopy applications.

It is a compact integrated detector, but compared to other similar systems it allows to change the active medium and use it for different purposes.

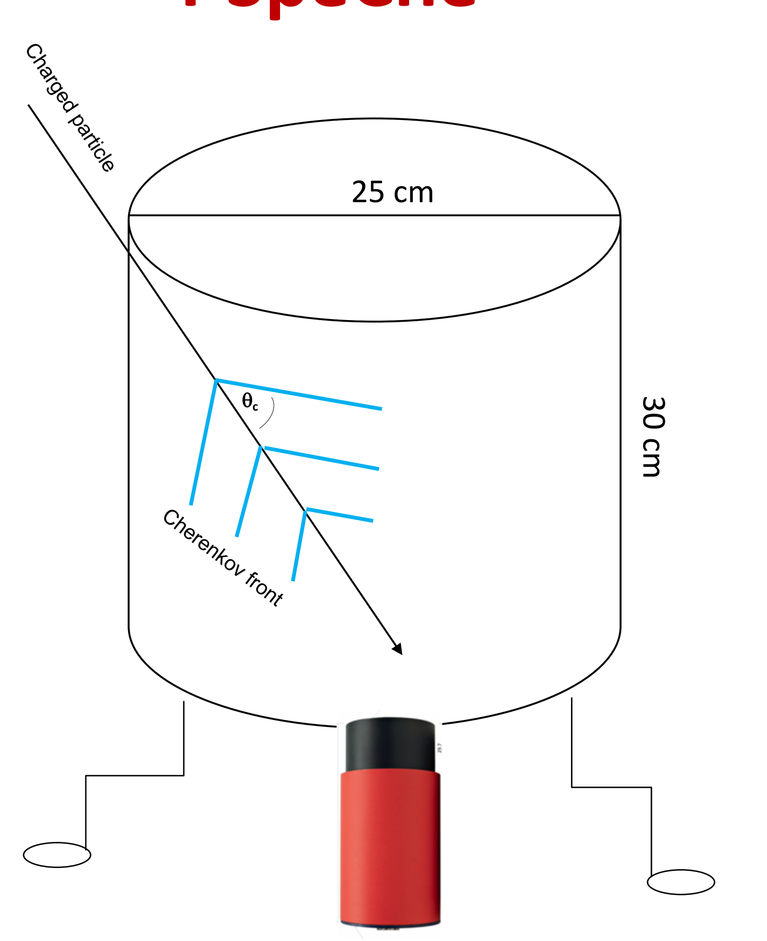
CsI(Tl), NaI(Tl), BGO, LYSO, LaBr

The water tank is connected to the SiPM matrix by means of EJ-5650 silicone rubber with the double function of optical joint and waterproofing.

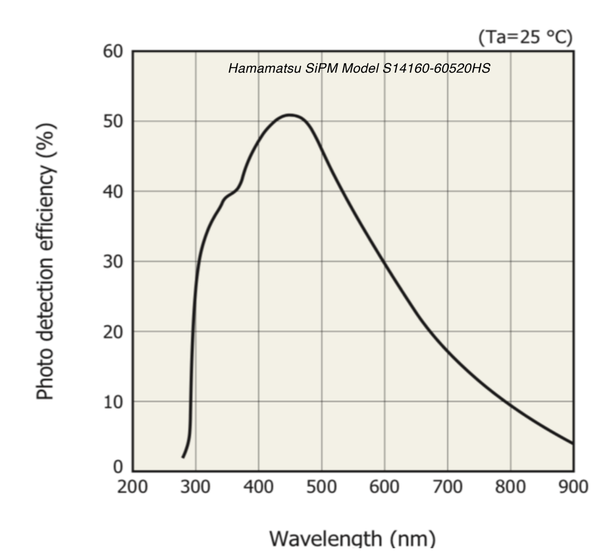
Silicone rubber EJ-5650



i-SpeChe



CAEN i-Spector



For the design of the radiator we have to take into account the shape, the dimension, the material of the tank and the active medium.
We choose an aluminum water tank with reflecting internal walls.
Using water and according to the follow

$$X_0\,(H_2O) = 36.08\ \mathrm{g\,cm^{-2}}\ ; \quad \frac{dE}{dx} = 1.992\ \mathrm{MeV\,g^{-1}\,cm^{-2}}; \quad \delta = 1\ \mathrm{g\,cm^{-3}}$$

30 cm length of water are enough to produce 3×10^4 photoelectrons and to absorb electrons from then background up to 30 MeV, selecting for the most part only muon.
With this length the effective area within which the Cherenkov ‘light pool’ is uniform is

$$A_{eff} \approx 0{,}75 \text{ x depth} = 22{,}5 \text{ cm}$$

We decide for a cylinder tank of 25 cm diameter.

The Cherenkov effect

When a charged particle travels in a dielectric medium with n>1 it radiates Cherenkov radiation if its velocity is larger than the phase velocity of light v>c/n or β > 1/n.
The Cherenkov angle θ_c between the direction of propagation of the light and the direction of motion of the particle is given by:

$$\cos\theta_c = 1/n\beta$$

The emitted light has wavelengths between the ultraviolet and the infrared, and assuming *n* is constant for a range of wavelengths, the number of photons produced per unit path is:

$$\frac{dN}{dx} = 2\pi\alpha z^2 \sin^2\theta_c\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)$$

In water n=1.33, $\theta_c \approx 41^\circ$ and considering l between 350 and 500 nm the light output is about 100 photons/cm

Outlook

The multipurpose i-SpeChe is the first detector aimed to familiarize high school students with the most important devices used in particle and astroparticle physics.
Next step of the project is to realize a RICH type detector to distinguish different particles through the characteristics of the Cherenkov footprint