Cherenkov Detector With Interchangeable Medium

Teomiztli (Puma Cósmico)

Aquino Maldonado Alma Teresa, Cabezas Montiel Luis Eduardo, De la Cruz Guzmán Marlon Uriel, García Páez Daniela, Jiménez Buendía Ilse Fernanda, Lomas Sandoval José Arturo, Rojas García Evelin.

An experiment proposal for the Beamline for Schools Competition

Escuela Nacional Preparatoria No.2 Universidad Nacional Autónoma de México
15th April, 2021, Mexico

Contents

1 Introduction

Cherenkov radiation is a phenomenon in which electromagnetic radiation is emitted in a dielectric medium, producing a cone-shaped sparkle of light. This happens when charged particles cross at greater speed than light travels in that medium [1] [2]. The angle of the generated light cone is given by the equation 1.

$$cos\theta_c = \frac{c}{nv} \tag{1}$$

This effect has been very useful within particle detectors for high energy experiments, cosmology and nuclear medicine. Cherenkov detectors consist of a dielectric material in which light caused by charged particles is produced and also by a compilation system of the produced light [1] [9]. Depending on the use of the detectors, dielectric materials that can generate the Cherenkov effect are selected, as well as the light compilation system; for example, photomultiplier tubes (PMT) are chosen too. The selection of materials will depend on the requirements and objectives of each detector. (Figure 1)

Figure 1: Diagram of a Cherenkov water detector. At the top, there is a phototube that collects the produced light in the medium [11].

An example in which Cherenkov detectors are used is the gamma-ray observatory, HAWC, which consists of 300 detectors. These record the particle passage created in atmospheric cascades produced by cosmic rays. Its goal is to observe the universe at energies between 100 GeV to 100 TeV. The observatory was built with purified water tanks that would serve as the dielectric medium in order to generate Cherenkov radiation and with photomultiplier tubes (PMT) to collect the generated light. Equally, containers have a tyvek cover to catch the most light in the PMT and an outer coating that prevents ambient light from entering [1] [8] [9].

The goal of this experiment is to build a Cherenkov detector with different dielectric mediums in order to compare the response, efficiency and energy resolution of the detector in each medium.

The mediums considered are water and glycerin. In each of them, the pulses generated by a beam of e^- and e^+ at different energies will be observed in order to compare their responses (2.6 GeV, 4 GeV and 6 GeV).

2 Why do we want to go?

We are senior year high school students at Universidad Nacional Autónoma de México, linked for our passion and curiosity for physics. Visiting and working with a synchrotron is a unique opportunity to gain experience since there are no particle accelerators in our country.

Winning the first prize would be a great achievement because it will help us to make a greater diffusion and promotion of science both in our university and in Mexico, thus helping more young people to get interested in the physics of particles and science in general. Furthermore, it would help us to reaffirm our vocation in the scientific investigation field.

As young and curious students, doing this project, in addition to filling us with knowledge, generated us new questions. For this reason, great opportunities like these help us to make our way so that one day we can help our society with the most valious tool of all: scientific knowledge.

3 Experimental Setup

In order to build the detector, three acrylic cylinders will be used. Two of these will contain a dielectric medium; one will contain water and the other glycerin.

3.1 Materials

3.1.1 Cylinders

- Two acrylic cylinders of 40 cm of length and 20 cm of diameter; each one will contain a different medium. The distance of 40 cm is proposed since the purific water has an attenuation of two meters and the distance that the synchrotron beam can cross goes from 20 to 30 cm before the particles are slowed down [10].
- A main acrylic cylinder will contain the secondary cylinder.

3.1.2 Coverage

The smallest cylinder will be covered inside with a reflective material and with an isolating material on the outside. This is with the following purpose:

- Reflective: it will allow to recover the biggest quantity of light generated by the charged particles and make the SiPM able to capture that light.
- Insulating: it will avoid the luminous pollution from the outside.

3.1.3 Medium

It will be a fundamental part of the experiment since it is where the Cherenkov light is produced. Three things were considered in order to choose the mediums to be compared:

- Refractive index: the higher it is with respect to the incident medium, there will be a greater probability that the charged particles will overcome the speed of light in that medium and be able to emit Cherenkov radiation [2] [7].
- Density: the medium density contributes to the amount of produced photons. [12].
- Dielectric constant: this value indicates the capacity of each material to accumulate electric charge and therefore energy [2][6].

Property	**Water**	**Glycerin**
Refractive index	1,3330	1,473
Density $[g/ml]$	1	1,26
Dielectric constant (at $20°C$)	80,4	42,5

Table 1: Comparative table of the properties of each proposed medium for the Cherenkov detector.

3.1.4 Silicon Photomultipliers

It was decided to use silicon photomultipliers (SiPM) as a photosensitive material for the detection of emitted photons. This is due to the fact that its operating voltage is between the 25 V and 70 V. They also have a photon detection efficiency (PDE) that is considered high because it is superior to 50% compared to the PMT quantum efficiency (QE) that is limited to 15% to 20% [4] [5].

The SiPM will be located at the bottom between the principal cylinder and the medium container, the latter will be covered on the inside with a reflective plastic and on the outside with a material that does not allow the external light to enter the system. (Figure 2)

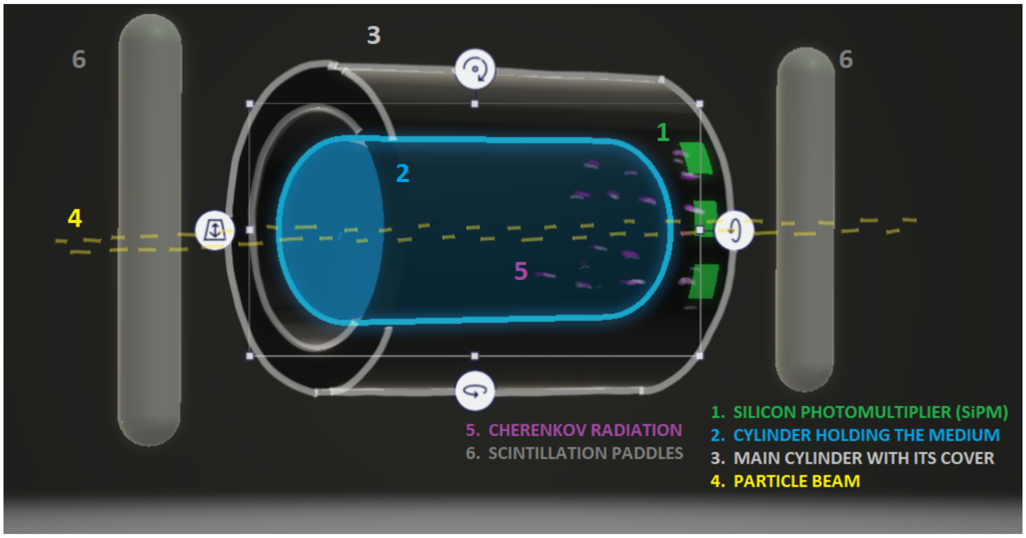

Figure 2: Cherenkov detector prototype diagram.

4 Methodology

For the detector characterization and calibration, two scintillation paddles are required in order to generate coincidence: the first one will be located between the beam and the detector, and the second one at the end of this. (Figure 3)

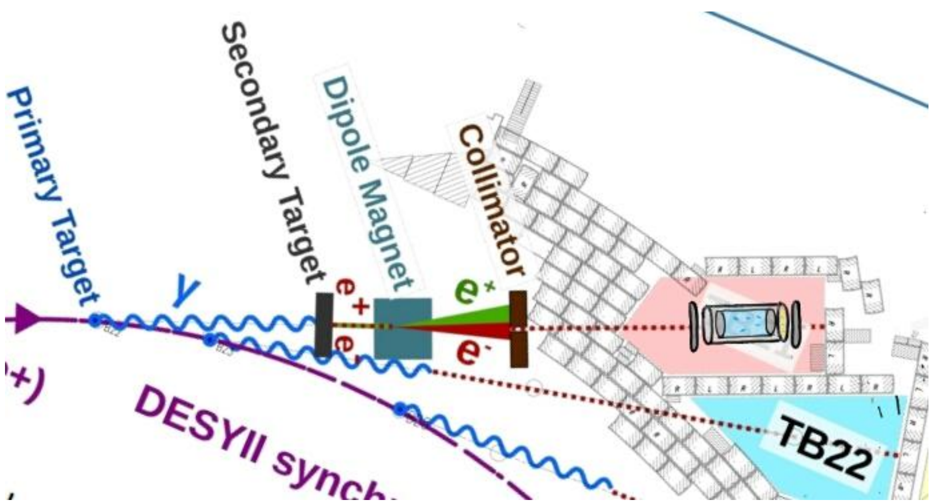

Figure 3: Detector and scintillation paddles location that are required to calibrate and characterize the detector.

It is proposed to use a beam of electrons and positrons at different energies (2.6 GeV, 4 GeV and 6 GeV) considering the rate of particles generated by those energies. Once the first medium has been characterized, obtaining the detector response, its efficiency, and energy resolution, the container of the first medium (water) will be replaced by the container of the second medium (glycerin) and the process will be repeated.

For the characterization it is sought to obtain the response of the detector and to obtain a graph of voltage versus time. (Figure 4)

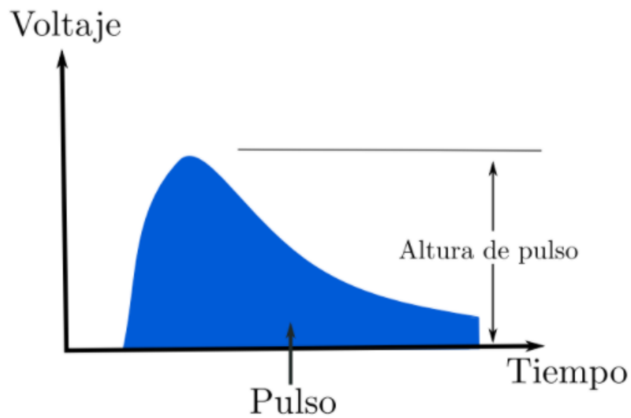

Figure 4: Graph of a detector pulse. The charge or amount of ionization is proportional to the integral of the pulse with respect to time. The shape of the pulse is characterized by having a rapid rise and an exponential decline [3].

To obtain the efficiency of the detector, we must consider the following expressions:

$$\varepsilon_{tot} = \frac{number\ of\ recorded\ events}{number\ of\ particles\ emitted\ by\ the\ source} \tag{2}$$

$$\varepsilon_{int} = \frac{number\ of\ recorded\ events}{number\ of\ particles\ hitting\ the\ detector} \tag{3}$$

$$\varepsilon_{geo} = \frac{number\ of\ particles\ hitting\ the\ detector}{number\ of\ particles\ emitted\ by\ the\ source} \tag{4}$$

To obtain the energy resolution of the detector, we will use the following equation:

$$Resolution = \frac{\Delta E}{E} \tag{5}$$

where $\Delta E = FWHM$ (Full Width Half Maximum).

Ideally, the obtained values would be as the Dirac delta function. Nevertheless, in reality it is expected to obtain a gaussian, which will be measured in FWHM terms (Figure 5). The lower this value is, the higher the detector resolution will be [3].

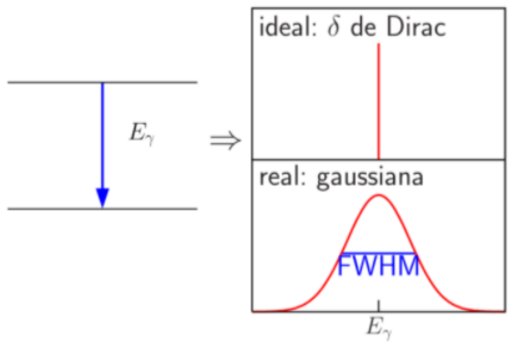

Figure 5: A monoenergetic radiation E is detected as a gaussian with a certain characteristic width for each kind of detector [3].

5 Acknowledgments

We would like to thank our advisors M.S. Laura González and Uriel García Elorza for motivating us every day during this process and for all the knowledge and support they offered us. We would also like to thank Dr. Alfaro Rubén for his advice and encouragement. It was a pleasure to work with your and, of course, the team's help.

6 References

[1] Carramiñana, A. et.al. (2007). Un Observatorio de Rayos Gamma de Gran Altura. HAWC @ México. 65. https://www.researchgate.net/publication/290743597_HAWC_Mexico.

[2] Bonilla Rosales, M. (2013). *Sistema de Adquisición de Datos para la Caracterización de Fotomultiplicadores para Experimentos de Altas Energías [Master's Thesis, Instituto Nacional de Astrofísica Óptica y Electrónica].*

[3] Guarín González, N. (2017). Eficiencia de un Detector Cherenkov en Agua para la Detección de Neutrones [Master's Thesis, Universidad Nacional de Cuyo].

[4] Agulló, M. (2008). Evaluación de los Fotomultiplicadores de Silicio (SIPM) Como Alternativa a los Fotomultiplicadores de Tubo de Vacía (PMT) en un FRONT-END Integrado Para Aplicaciones PET. Universidad Politecnica de Valencia https://riunet.upv.es/bitstream/handle/10251/\13140/memoria.pdf;jsessionid=8B613493798BC9520ED188027BB3277B?sequence=1

[5] Broadcom. (2018). AFBR-S4N44C013 4×4 NUV-HD Silicon Photo Multiplier Array. Broadcom. http://www.farnell.com/datasheets/2723105.pdf

[6] Hyperphysics. (s.f.). Dielectric constants. Hyperphysics
http://hyperphysics.phy-astr.gsu.edu/hbasees/Tables/diel.html

[7] (2021). Tanques de agua Cherenkov. The High-Altitude Water Cherenkov Gamma-Ray Observatory. https://www.hawc-observatory.org/observatory/tanks.php

[8] (2021). El observatorio de Rayos Gamma HAWC. The High-Altitude Cherenkov Gamma-Ray Observatory. https://www.hawc-observatory.org/

[9] Andrew J. Smith et.al.. (2015). HAWC: Design, Operation, Reconstruction and Analysis. 31 agosto 2015, de The 34th International Cosmic Ray Conference,
website: https://arxiv.org/abs/1508.05826

[10] (2015). Detectores Cherenkov de agua [Figure 1]. https://halley.uis.edu.co/fuego/el-proyecto/conceptos-y-tecnicas-basicas/detectores-cherenkov-de-agua/

[11] Damonte, L. C. (2017). Pasaje de partículas cargadas por la materia. Efecto Cherenkov. Bremsstrahlung. unlp.
http://www2.fisica.unlp.edu.ar/materias/Nucleo/Teorias_2017/Clase%2023.pdf