Cherenkov radiation in a polarized dielectric medium

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Why we want to take part

Our team is composed of future physicists, engineers and scientists from Liceo Scientifico Antonio Pacinotti, Cagliari. We are extremely passionate individuals, who first came in contact with particle physics thanks to the fruitful, hands-on working environment of the EEE program.

We think that a once-in-a-lifetime opportunity such as BL4S would be the perfect chance to prove ourselves and work alongside CERN's brilliant professionals, whose guidance would undoubtedly enhance our level of understanding of this fascinating subject.

Being chosen as one of the two most deserving teams in this competition would be a remarkable achievement for ourselves, giving us the chance to motivate our younger fellow students to pursue their ambitions.

Experiment proposal

The speed of light is known to be a universal constant with a value of (c = 299 792 458 m/s). While such a statement is true for a photon travelling through a perfect vacuum, the same can't be said if considering the medium to be any other physical material. Light is in fact slowed down by the material through which it is propagating, we call the speed of light value specific to each material its phase velocity. Matter can therefore be accelerated at velocities greater than the speed of light in a dielectric medium and, when this occurs, a phenomenon known as Cherenkov effect is manifested.

The Cherenkov effect is electromagnetic radiation with peak intensity in the blue-violet region of the electromagnetic spectrum, which represents the renowned label of this phenomenon [1], [2].

In the case of Cherenkov radiation, emitted photons are the result of momentary electric dipoles induced by the transitory charged particle's electric field. The charges in the molecules of the radiator will return to their ground state once the charged particle has passed, releasing their momentary potential energy in the form of a photon at a characteristic Cerenkov angle. If we think of the aforementioned photons as spherical wavefronts emanating from the accelerating particle, it comes as a consequence to

Hyugens' principle that they will constructively interfere only as the speed of the charged particle is larger than the local speed of light (phase velocity), given by:

$$v = \frac{c}{n} \quad (1)$$

Once constructive interference between the EM waves is achieved, detectable light will be emitted. This behavior is somewhat analogous to the Mach cone produced by a supersonic aircraft through air, with the only difference being the nature of the waves (electromagnetic - pressure) and the phase velocity (relative speed of light - speed of sound).

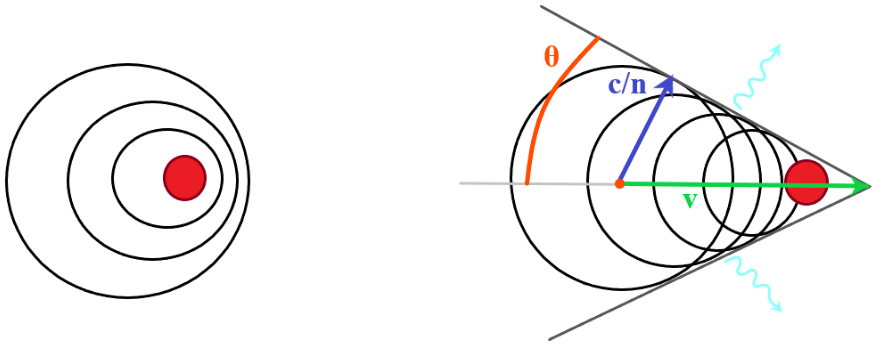

Fig.1: Hyugens' principle and the Cherenkov effect for a subluminal charged particle and a superluminal charged particle

The goal of the experiment we propose is to observe the influence of a strong electric field, such as to polarize the medium, on the Cherenkov light emission intensity. The electric field is to be varied in order to study and characterize its effects on the emission of photons by comparing it with the emission from the non-polarized radiator. We expect the electric field to induce its own dipoles on the radiator's molecules, therefore orienting them with respect to the field and as a result "stiffen" the dielectric, which will now present a smaller degree of angular displacement on its molecules. According to our prediction, polarization will decrease the emitted power and consequently the intensity of photons. The number of Cherenkov photons produced over a path (L) can be calculated by simplifying the Frank-Tamm formula for a unitary charge and straight trajectory. [3], [4], [5], [6]

$$\frac{dN}{dE} = 370L\left(1 - \frac{1}{n_p^2\beta^2}\right) \quad (2)$$

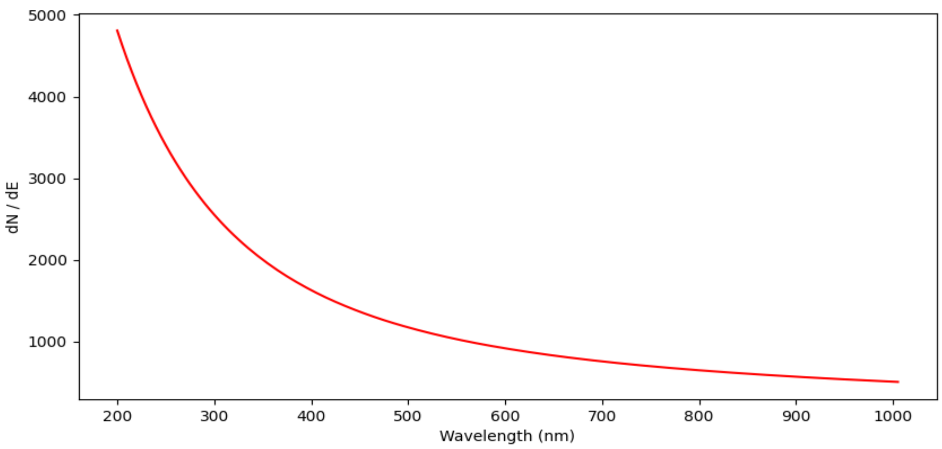

Fig. 2: Python simulation of the Frank-Tamm formula through a 100mm water radiator, the number of photons per unit-wavelength are shown as a function of wavelength.

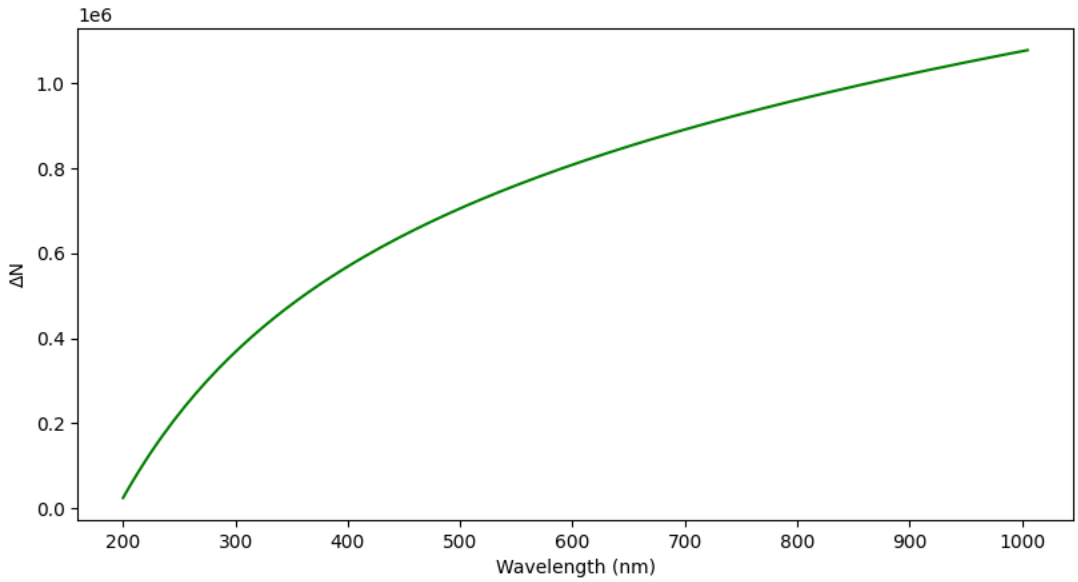

Fig. 3: Numerical integration of the Frank-Tamm formula with respect to wavelength

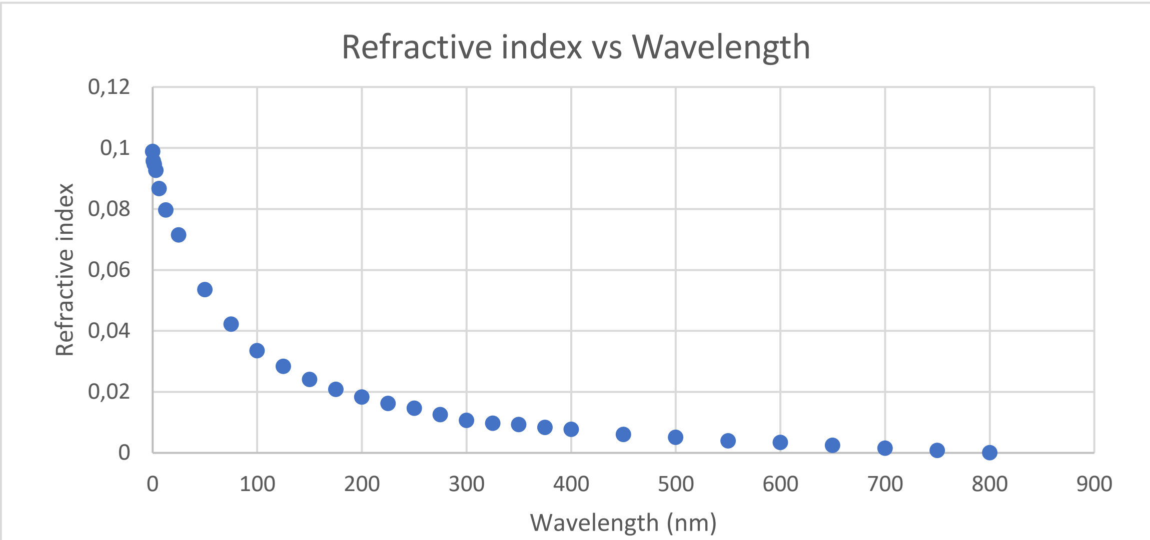

Fig. 4: Change in phase refractive index as a function of wavelength for water at 20˚C

Experimental setup

The proposed experiment starts by providing a pure electron beam to interact with the polarized Cherenkov detector.

This can be done by deflecting away the secondary beams of charged particles by the use of two bending magnets so that the neutral gamma rays remaining unaltered in their trajectory can interact with a 5mm lead converter assembly, that converts the gamma photons into positron/electron pairs by pair production. The matter and antimatter electrons are then deflected once more, and filtered in their velocity using a momentum collimator. This method is able to provide a purity greater than 90% at energies below 3GeV [7].

Given a pure electron beam, we are brought to the heart of our experiment: the polarized Cherenkov radiator and detector assembly.

In an effort to prevent deflection of the incoming charged particle by the strong electric field, the beam will have a parallel trajectory to the field lines.

In order to extract meaningful data from our experimental setup, we must accurately select the radiator material and its dimensions. The main concerns regarding the radiator's material are:

- Its ability to be polarized, i.e. high susceptibility and dielectric constant;
- Transparency to light in the Cherenkov wavelength;
- Non-flammability;
- A high dielectric strength, to allow for an increase of the electric field with reduced risks of dielectric breakdown;
- A high refractive index, to permit the use of lower energy electrons;

The specific radiator materials are to be chosen in-situ together with the BL4S experts. Our research and experience from previous competition-winning experiments has led us to identify the following as most fitting:

Material	Demineralized water	Glycerin
Refractive index	1.37	1.47
Dielectric strength	0,15 MV/cm	0,2 MV/cm
Permittivity constant	80	42
Susceptibility constant	79	41

As far as the dimensions of the radiator are concerned, we have looked into the idea of a high aspect-ratio structure (in order to approximate the field as constant). The actual thickness value is the result of a design compromise that has to balance a reasonable breakdown voltage and total number of photons produced to give a signal relevant for the PM tubes (linear with distance), with an effective polarization of its own molecules.

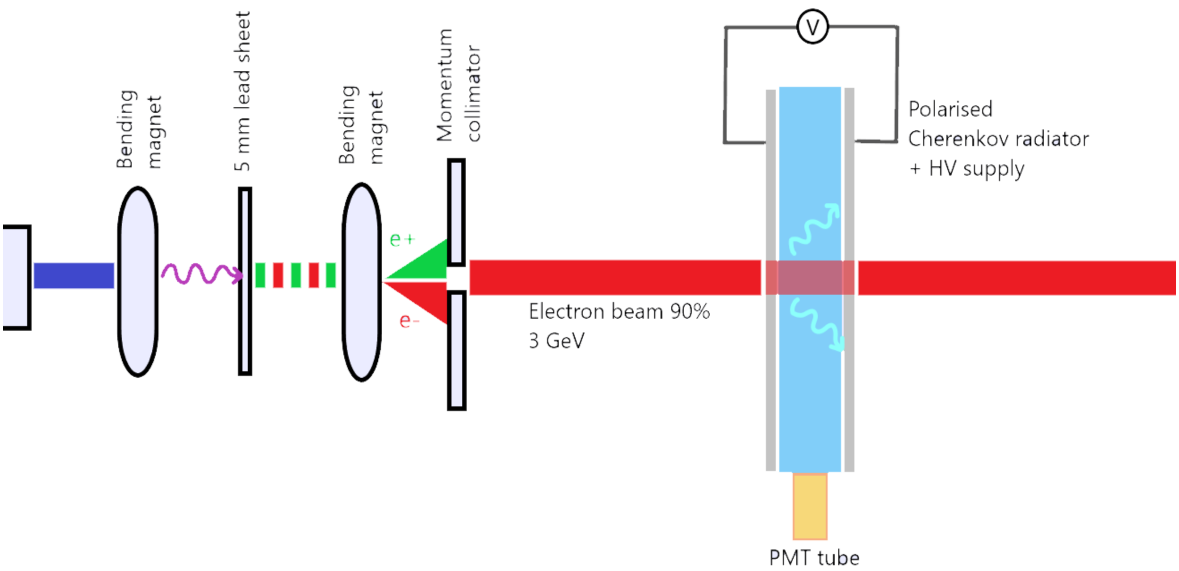

Fig. 5: Conceptual representation of the proposed experimental setup

What we hope to take away

When we first came across the Beamline for Schools event, we immediately started brainstorming for new and creative experiment ideas, knowing that we would have needed all of our abilities, commitment and team working skills in order to develop this project from the ground up.

The development of our polarized Cherenkov radiator proposal has given us the occasion to greatly improve our knowledge by coming into contact with the practical, applications of the subjects we enthusiastically studied since as long as we can remember. Working as a team in such a challenging undertaking would certainly be an experience we will always bring within ourselves for years to come.

Acknowledgements

It wouldn't be possible for us to conclude this proposal without thanking our school and the Beamline for Schools team for the amazing opportunity offered to us. Our most heartfelt thanks go to our amazing teachers: Prof. C. Vacca, Prof. S. Loggia, Prof. R. Puzzanghera for their needful and thorough counsel and suggestions, as well as Prof. C. Cicalò along with the other members of our school's wonderful EEE team.

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