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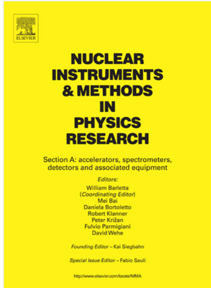

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Cherenkov light imaging in particle and nuclear physics experiments

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Abstract

This article describes Cherenkov light imaging techniques used in the particle and nuclear physics experiments, concentrating on the author's personal overview of selected recent counters.

1. Introduction

Substantial R&D for Cherenkov ring imaging (RICH) detectors is on-going in particle and nuclear physics. Much of this work was discussed in detail at the RICH2016 workshop. This article provides an overview of several detectors no being operated or developed for use in particle and nuclear physics experiments.

Cherenkov radiation is an electromagnetic shock wave that occurs when the velocity, v, of a charged particle is larger than the velocity of light, c, in a medium. Three important equations describe the Cherenkov ring image [1]. 1) The particle needs to be faster than a threshold, v_{th}, to generate Cherenkov radiation, which depends as

$$\beta_{th} \equiv \frac{v_{th}}{c} = \frac{1}{n(\lambda)},$$

where $n(\lambda)$ is the refractive index of the medium, which varies with the wavelength of light, λ. 2) Cherenkov light is emitted in a cone shape with the Cherenkov angle, θ_c, where

$$\cos\theta_c = \frac{1}{\beta n(\lambda)}.$$

Therefore, we can obtain β information from Cherenkov ring detection. 3) Emitted number of photons, N, is not so much and varies with λ, like

$$\frac{d^2N}{dx d\lambda} \sim \frac{1}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right),$$

which is important for detector design.

For the Cherenkov ring imaging, of course, the radiation should be happened in the limited region and the Cherenkov photons need to be collected by (pixeled) photon sensors, as shown in Fig 1. Therefore, the radiator length, L, affects to the number of photons and also the ring-image resolution on the sensors. We have choice of optics design, proximity or mirror focusing system to improve the angle resolution. The sensitive wavelength and pixel size of photon sensor is also important for the detector design. Other notes on the reality is the Chromatic dispersion by the refractive index change as a function of λ, and of course, detector space, cost and so on.

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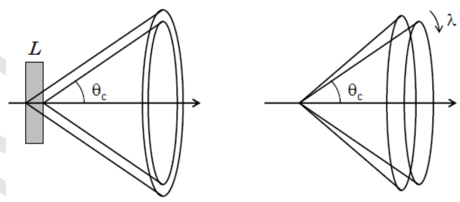

Figure 1: Image of Cherenkov light emission. (Left) Cherenkov light emits from limited radiator region. (Right) Cherenkov angle θ_c depends on the wavelength of light λ.

In this article, I provide a short, and selective, personal overview of several recent counters. I have found it convenient to categorize them by radiator type, namely gas, aerogel and quartz, leaving liquid-based detectors aside. The refractive indices used vary from 1.5 to just above 1, in order to cope with particle target momenta in a range from 1 to 100 GeV/c.

2. RICH using gases

Basically, in a RICH detector using a gas radiator, Cherenkov light is emitted along a line source defined by the particle's path, with a length defined by the radiator windows, and then imaged by a focusing mirror onto photon sensors. The typical image has the shape of a ring whose radius depends on the Cherenkov angle. Gas radiators have relatively low refractive indices, which means higher β thresholds, and thus are appropriate for high particle momenta. However, the Cherenkov angle and the number of photons per unit radiator length is rather small, so that the detector needs a long radiator space.

The two Gas RICH detectors of the LHCb experiment have been operating well for several years [2]. They are located in the forward region for proton-proton collisions providing excellent π, K, proton separation for the produced particles. RICH-1 is located closer to the interaction point, uses the higher index gas, and targets the lower momentum particles up to 60 GeV/c. RICH-2 has the lower index gas and targets the higher momenta up to 100 GeV/c. Both detectors utilize large focusing mirror optics as shown in fig. 2. Photons bounce off two mirrors and