Rich note 4
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A Novel LiF Radiator for RICH Detectors

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A multifaceted LiF radiator produces more Cherenkov light and has better resolution per photon than a flat radiator slab when used in a ring imaging Cherenkov counter. Such a system is being considered for the CLEO III upgrade.

1. Introduction

Ring imaging Cherenkov detectors (RICH) are capable of providing excellent identification of charged particles. Several systems have been implemented in hadron beams and e^+e^- collider experiments [1]. A RICH detector with a LiF radiator and photon detector consisting of CH_4 and TEA vapor has been successfully tested by the Fast-RICH group at CERN [2]. Using fast VLSI electronics, an average of 10.4 photoelectrons were detected, for an incident track angle of 25^o with respect to the radiator, with a resulting resolution per track of 4.2 mrad.

We use as a benchmark the separation between pions and kaons at a momentum of 2.8 GeV/c, which is the upper limit of particle momentum from B decays from the $\Upsilon(4S)$ resonance at a symmetric e^+e^- collider. (All simulations in this paper use 2.8 GeV/c pions or kaons.) Since LiF has a refractive index of 1.5 at 150 nm, which is the center of the useful wavelength range in this system, the K/π separation at 2.8 GeV/c is 12.8 mr.

2. Flat Radiator Configuration

The detector we envision for the CLEO III upgrade fits between the CsI electromagnetic calorimeter and a new drift chamber [3]. It is approximately cylindrically symmetric with the LiF radiators in the form of tiles ($\approx$17x17 cm^2) at an inner radius of 82 cm and a gap of 16 cm between the radiator and the entrance window of the wire proportional chamber. The length of the radiators is 234 cm, while the photon detectors are 250 cm long. The photon detector is similar to that used in the CERN tests, but differs because the pads are 7.5 x 7.5 mm^2, and the pulse height on each pad is measured.

A system of flat 1 cm thick LiF radiators must have the angle of the incident charged track be larger than about 6^o with respect to the normal in order to avoid total internal reflection of all the Cherenkov light. Thus in the center of a cylindrically symmetric detector the radiators must be tilted. An angle of about 20^o is required to have adequate Cherenkov light. Even so, most of the Cherenkov light is lost. If plane radiators were to be used, the CLEO III system would have 16 sections along the z-axis of which 4 would be tilted.

The angular resolution per detected photon is comprised of several sources. The most important are the chromatic error, which results from the variation of the index of refraction with the wavelength, the emission point error, which results from the lack of knowledge about where the photon is emitted, and the position error in detecting the photon. The total error, for high momentum tracks, grows from about 13.5 mr to almost 15 mr as the angle of the track with respect to the normal increases from $\cos\theta$ of zero to 0.82. This corresponds to a $\approx$3.7 mrad resolution per track. The remaining calculations in this paper, however, assume a 20% degredation in photoelectron yield, which gives about 4.1 mrad resolution per track for the plane radiator.

3. "Sawtooth" Radiator Configuration

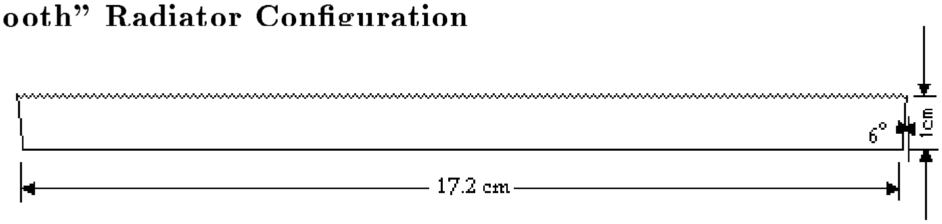

Figure 1: A possible "sawtooth" design with 1 mm deep grooves.

To get more light out of the LiF it is advantageous to facet the surface where the Cherenkov light exits. (See [4] for a more detailed description of this work.) One design with 45^0 facets is shown in Fig. 1. This design has 1 mm deep facets. Other designs with facets as deep as 5 mm are possible. The smaller facets give somewhat better performance in that the spread in thickness of the radiator is much smaller. The grooves run along the 234 cm length of the detector, i.e. along the z-axis. To explore the potential of such radiators, we performed Monte Carlo simulations of different facet angles always keeping the average thickness of the radiator at 10 mm. Quantities of interest are the angular resolution per photoelectron, the average number of photoelectrons, the resolution per track and the probability of pions faking kaons. The angular resolution per photon changes because of differences in the chromatic error, which is influenced by the angle of the photon with respect to the normal as it leaves the surface [5].

In order to compare different facet angles expeditiously, we use GEANT simulation with hadronic interactions removed. In Fig. 2(a) we show the average number of detected photoelectrons as a function of incident track angle, $cos\theta$, for different teeth angles, where larger angles refer to sharper teeth. In order to more closely simulate the actually detector geometry, with a fixed length photon detector, we included mirrored ends with a reflectivity of 80% at 150 nm. Also shown is the flat radiator for the non-tilted sections. The optimum angle is close to 45^o. (Note, the Cherenkov angle is 48^0 for relativistic tracks.)

In Fig. 2(b) we show the resolution per photoelectron. Also here the optimum angle is close to 45^o. The angular resolution per track is shown in Fig. 2(c). Although the angular resolution typically characterizes the detector performance the image

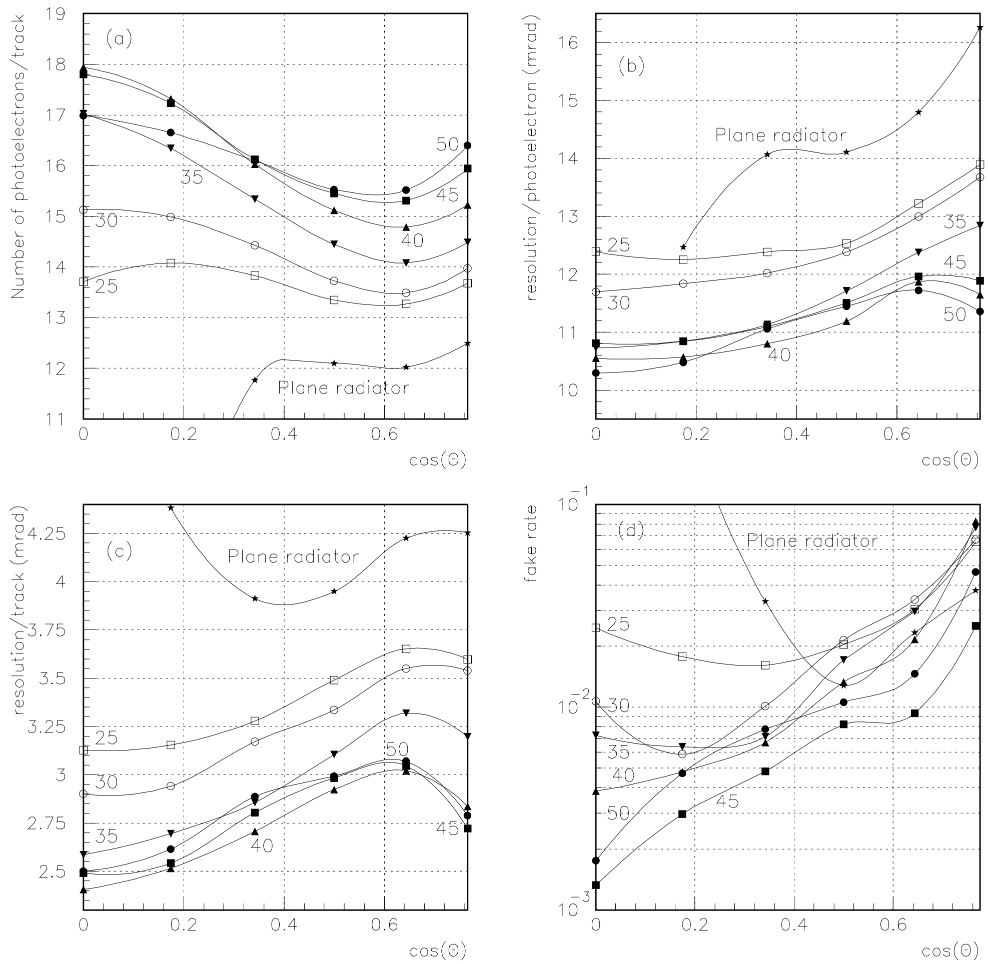

Figure 2: (a) The average number of photoelectrons detected as a function incident track angle for different "tooth" angles. The expected photoelectron yield has been degraded by 10%. (b) The resolution per photoelectron. (c) The resolution per track. (d) The probability for a 2.8 GeV/c pion to fake a kaon for a 95% pion efficiency requirement.

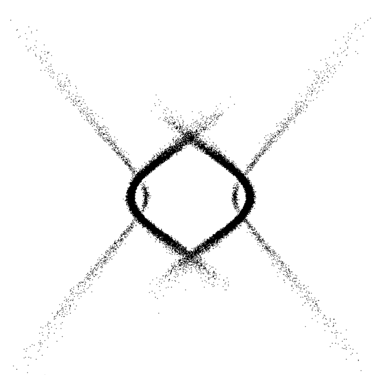

Figure 3: The image pattern for tracks normal to the radiator.

of the photoelectrons here has a complicated shape. In Fig. 3 we show the light pattern for a track normal to the radiator, for a 45^o tooth angle. Recall, that for a flat plane radiator no light exits from radiator surface. The image consists of two intense hyperbolas resulting from light which directly exits the radiator surface, and two lightly populated hyperbolas which result from photons which experience one reflection from the sawtooth surface, either before or after exiting from the surface. There is only $\approx$6% of the light in these more extended curves.

This complex pattern causes the fake rate to be somewhat larger than what would be implied by the angular resolution per track and the difference in Cherenkov angle between different particle species, especially at large values of $cos\theta$. In Fig. 2(d) we show the probability for pions to fake kaons at momentum of 2.8 GeV/c as a function of $cos\theta$, for a 95% efficiency for the pions. It is possible that the algorithm that assigns the hits to a particular section of pattern with a particlular weight can be improved. We also show the fake rate for a plane 1 cm thick radiator. The sawtooth has less of an advantage at large $cos\theta$, but is still better than the plane radiator.

Combining these considerations, we find that the best performance in terms of lowest fake rates is given by 45^o teeth.

4. Conclusions

Simulations show that a multifacted radiator with 45^o grooves gives substantially more photons, better angular resolution per photon, and lower fake rates than plane crystal radiators. Furthermore such "sawtooth" radiators eliminate the need for tilted radiator tiles. We have successfully machined sawtooth surfaces [6]. We are currently working with OPTOVAC, North Brookfield, Mass. to obtain a good surface polish.

References

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