The CLEO III RICH Detector

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CLEO III upgrade was completed with the integration of Ring Imaging Cherenkov (RICH) detector for charged particle identification. The design of this cylindrical detector consists of LiF crystal radiators and multi-wire proportional chamber photon detectors coupled through a $N_2$ filled expansion gap. Early performance on $K/\pi$ separation is presented.

1. Introduction
In the past 20 years of its existence, the CLEO detector has been associated with many discoveries and precision measurements of heavy flavour physics. The latest generation of the detector, the CLEO III, has been upgraded. One of the new features of the CLEO III detector is its particle identification system, the Ring Imaging Cherenkov (RICH) detector.

The basic principle of the differential Cherenkov detector is, given by the relation $\Delta \cos^2 \theta = \Delta m^2 / (n^2 p^2)$, where $n$ is the refractive index of LiF, $p$ is momentum and $\Delta m^2$ is the mass square difference between two particles. In order to achieve efficient particle identification with low fake rates, a design goal of $4\sigma$ $K/\pi$ separation at 2.65 GeV was set. This momentum is given by two-body B decays. At this momentum, difference between $K/\pi$ Cherenkov angle, $\Delta \theta_\gamma = 14.4$ mrad. Along with the $1.8\sigma dE/dx$ identification from the drift chamber, one requires a per track angular resolution of $\sigma_{\theta_{\gamma,k}} = 4$ mrad. Using a naive approximation $\sigma_{\theta_{\gamma,k}} = \sigma_{\theta_\gamma} / \sqrt{N_\gamma}$, the benchmark of RICH design was therefore to have an average of 12 photons with a resolution of 14 mrad per photon.

2. Detector design
CLEO RICH detector design was mainly constrained by two factors, (a) only 20 cm of radial space available between the drift chamber and the calorimeter with 2.5 m of length (80% of solid angle) and (b) for good performance of the EM calorimeter RICH material had to be less than 15% of the radiation length.
The overall RICH design is a cylinder with compact photon detector modules on the outer layer and radiator crystals on the inner layer, forming a 12° sector in azimuth. The driving constraints for the design in many respects was the choice of Triethylamine (TEA) as a photon-absorber, as it is chemically aggressive and also shows a high quantum efficiency in the VUV regime (135–165 nm).

Crystal Radiators: The basic design consists of 30 rows of crystal along the axis of cylinder with each row containing 14 LiF crystals, of dimension ∼ 175×172×10 mm³ mounted on a carbon fiber cylinder. Due to high refractive index of LiF (n ∼ 1.5), a large number of cherenkov photons are internally reflected, resulting in partial images. At the normal track incidence all photons are reflected back due to total internal reflection. In order to fix this situation, a novel radiator geometry is used in the central region (120 crystal). The light emitting surface of the radiator is cut with a profile resembling the teeth of a saw, and therefore is referred to as the sawtooth radiator.

Expansion volume: This is essentially an empty space, 157mm in radial distance, filled up with pure N₂ gas. O₂ and H₂O contamination is kept less than 10 ppm to avoid any loss of photons in this volume. Transmission efficiency is more 99% at 150 nm.

Photon detectors: These are photosensitive asymmetric multiwire proportional chambers, filled with CH₄ carrier gas bubbled through liquid TEA at 15° (5.5% vapour concentration) and having 2mm thick CaF₂ windows with 100µm thin Ag strip providing one of the cathode planes. TEA has a peak QE of ∼ 33% at 150 nm and a bandwidth of 135-165 nm. Anode wires are made of 20µm diameter Au-W and the array of 8.0×7.53 mm² cathode pads on outer surface is used to collect induced image charge. This is an optimal design to maximise photon conversion efficiency (ℓ_{abs} = 0.56 mm at 150 nm) and anode-cathode charge coupling by having the wire-pad gap be as small as 1 mm.

Readout Electronics: The choice of readout electronics is governed by the exponential charge distribution of single photoelectron avalanche and also by the time allowed for the readout. Analog front-end electronics with low noise and high dynamic range are used, which has very low rms noise ENC = 130e⁻ + 9C_{det}e⁻/pF ≈ 150e⁻ for modest C_{det} ≈ 2pF.

The charge information is necessary to determine the centroid of the photoelectron as well as disentangle the overlap of two nearby photons. The latter requires high segmentation. Given the modest pass size over large detector area, there are 230,400 pads in total. Sparsification works well since occupancy is low (<1%).

3. Performance

The RICH detector was installed along with other subdetectors in CLEO in Aug 1999 and the first data were collected starting from Nov 1999. The detector performance has been satisfactory. The transparency of expansion volume is more than 99% at 150 nm. The stable high voltage system has been successfully operated at different voltage setting to choose optimal operation voltage. The average detected
charge per Cherenkov photon is $\sim 2.2 \times 10^4$ electrons. The electronic noise has a mean value $\sim 500e^-$, with common mode subtraction and $\sim 790e^-$ including the coherent component.

During the engineering run, preliminary study of detector performance was mainly based on the Bhabha events. The angular resolution is very close to what was expected. Some observed deterioration is due to noise and lack of proper alignment. The results are shown in Table 1.

As a first attempt at physics analysis, $D^0 \rightarrow K^-\pi^+$ and $D^{*\pm} \rightarrow K^-\pi^+\pi^{\pm}$ were reconstructed. For 80% efficiency of $D^0$ in the signal region, RICH could reduce the background by an order of magnitude. Similarly $D^{*\pm}$ was reconstructed, removing virtually all background from $M_{D^{*\pm}}-M_{D^0}$ peak. These distributions are shown in figure 1.

These results are preliminary. Using better tracking the Cherenkov angle resolution should improve.

4. Conclusion

The engineering run has proven the satisfactory performance of the RICH detector, which fulfilled its benchmark. Since Aug 2000, CLEO has been taking physics data. The RICH detector will be an important element for the upcoming CLEO physics results.

References

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2. J. Séquist et al., Nucl. Instr. Meth. A350 (1994) 430.