PROGRESS TOWARDS CLEO III
THE SILICON TRACKER AND THE LIF-TEA RING IMAGING CHERENKOV DETECTOR

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Marina Artuso
Department of Physics,
Syracuse University,
Syracuse, New York 13244-1130
e-mail: artuso@physics.syr.edu

We describe the two major components of CLEO III: the Silicon Vertex Detector and the Ring Imaging Cherenkov Detector (RICH). The Silicon Vertex Detector is a four layer barrel-style device which spans the radial distance from 2.5 cm to 10.1 cm and covers 93% of the solid angle. It is being constructed using double-sided silicon sensors read out by front end electronics devices especially designed for this application. The RICH system consists of LiF radiators and multiwire proportional chambers containing a mixture of CH4 and TEA gases. The radiators are both flat and “sawtooth.” Results from a test beam run of final CLEO III RICH modules will be presented, as well as test beam data on sensors to be employed in the Silicon Vertex Tracker.

1 Introduction

The Cornell $e^+e^-$ collider (CESR) is currently being upgraded to a luminosity in excess of $1.7 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$. In parallel the CLEO III detector is undergoing some major improvements.

One key element of this upgrade is the construction of a four layer double-sided silicon tracker. This detector spans the radial distance from 2.5 cm to 10.1 cm and covers 93% of the solid angle surrounding the interaction region. The outermost layer is 55 cm long and will present a large capacitive load to the front-end electronics. The innermost layer must be capable of sustaining large singles rates typical of a detector situated near an interaction region.

A novel feature of CLEO III is a state of the art particle identification system that will provide excellent hadron identification at all the momenta relevant to the study of the decays of B mesons produced at the $\Upsilon(4S)$ resonance. The technique chosen is a proximity focused Ring Imaging Cherenkov detector (RICH) in a barrel geometry occupying 20 cm of radial space between the tracking system and the CsI electromagnetic calorimeter.

The physics reach of CLEO III is quite exciting: the increased sensitivity of the upgraded detector, coupled with the higher data sample available, will provide a great sensitivity to a wide variety of rare decays, CP violating asymmetries in rare decays and precision measurements of several Cabibbo-Kobayashi-Maskawa matrix elements.

2 Vertex Detector Design

The barrel-shaped CLEO III Silicon Tracker (Si3) is composed of 447 identical sensors combined into 61 ladders. The sensors are double sided with $\varphi$ readout on the n side and z strips on the p side. The strip pitch is 50 $\mu$m on the n side and 100 $\mu$m on the p side. Readout hybrids are attached at both ends of the ladders, each reading out half of the ladder sensors. More details on the detector design can be found elsewhere. Sensors and front end electronics are connected by flex circuits that have traces with a 100 $\mu$m pitch on both sides, being manufactured by General Electric, Schenectady, New York.

All the layers are composed of identical sensors. In order to simplify the sensor design, the detector biasing resistors and the coupling capacitors have been removed from the sensor into a dedicated R/C chip, mounted on the hybrid. Another key feature in the sensor design is the so called “atoll” geometry of the p-stop barriers, using isolated p-stop rings surrounding individual n-strips. Furthermore a reverse bias can be applied to the p-stop barriers through a separate electrode. Thus the parasitic capacitance associated with these insulation barriers can be significantly reduced with a corresponding reduction of the sensor noise in the frequency range of interest.

The middle chip in the readout chain is the FEMME preamplifier/shaper VLSI device. It has an excellent noise performance. At the shaping time of $2\mu$s, well matched to the CLEO III trigger decision time, its equiv-
alent noise charge is measured as:

\[ ENC = 149e + 5.5e/pF \times C_{in}, \]  

(1)
giving satisfactory noise performance also with the high input capacitances in the outer layer sensors. More details on the design and performance of this device can be found elsewhere. The last chip in the readout chain is the SVX_CLEO digitizer and sparsifier. Both these chips are manufactured utilizing radiation-hard CMOS technology from Honeywell.

3 The Si3 test beam run

The silicon sensors have been tested in several test beam runs that took place at CERN in the last few months. The sensors, flex circuits, and R/C chips used were the same ones planned for the final system. However the readout electronics used was not the combination of FEMME + SVX_CLEO, but the low noise VA2 chip produced by IDE AS, Norway with digitization implemented in the remote data acquisition system.

The data were collected inserting the Si3 sensor in the test beam set-up used by the RD42 collaboration to test their diamond sensors. A 100 GeV \( \pi \) beam was used and the silicon sensor was inserted in a silicon telescope composed of 8 microstrip reference planes defining the track impact parameters with a precision of about 2 \( \mu m \). Two data sets were collected. The first one contains 300,000 events with tracks at normal incidence and different bias points. The second one consists of about 200,000 events at \( \theta = 0 \) and \( \theta = 10^5 \). The probability distribution of the variable \( \eta \) defined as \( \eta = Q_L/(Q_L + Q_R) \) (refering to the relative location of two adjacent strips where at least one of them recorded a hit) has been mapped and has been used in a non-linear charge weighting to reconstruct the track hit location. Fig. 1 shows the hit resolution achieved on the n-side with a detector bias of 100 V and a p-stop reverse bias of 20 V. A value of \( \sigma \) of 6 \( \mu m \) is quite impressive for a track at normal incidence. The expectation for a 50 \( \mu m \) strip pitch is about 9 \( \mu m \), as the charge spreading due to diffusion does not provide appreciable signal in the neighboring strip unless the track impact point is at the periphery of the strip. The higher resolution achieved in this case is attributed to an increase in charge spread due to the reverse biased p-stops. In fact the ability to modulate the reverse bias of the p-stops has allowed the tuning of this charge sharing for optimum resolution and may be of interest for other applications.

4 Description of the CLEO III RICH System

The CLEO III RICH system is based on the ‘proximity focusing’ approach, in which the Cherenkov cone, produced by relativistic particles crossing a LiF radiator, is let to expand in a volume filled with gas transparent to ultraviolet light before intersecting a photosensitive detector where the coordinates of the Cherenkov photons are reconstructed. The photodetector is a multiwire proportional chamber filled with a mixture of Triethylamine (TEA) gas and Methane. The TEA molecule has good quantum efficiency (up to 35%) in a narrow wavelength interval between 135 and 165 nm and an absorption length of only 0.5 mm.

The position of the photoelectron emitted by the TEA molecule upon absorption of the Cherenkov photon is detected by sensing the induced charge on an array of 7.6mm \( \times \) 8 mm cathode pads. The probability distribution for the charge in the avalanche initiated by a single photoelectron is exponential at low gain. This feature implies that a low noise front end electronics is crucial to achieve good efficiency. A dedicated VLSI chip, called VA_RICH, based on a very successful chip developed for solid state application, has been designed and produced for our application at IDE AS, Norway. We have acquired and characterized all the hybrids necessary to instrument the whole RICH detector, a total of 1800 hybrids containing two VA_RICH chips each, corresponding 230,400 readout channels. We have fully characterized all of them and for moderate values of the input capacitance \( C_{in} \), the equivalent noise charge ENC is found to be about:

\[ ENC = 130e^- + (9e^-/pF) \times C_{in}. \]  

(2)
The traces that connect the cathode pads with the input of the preamplifier in the VA_RICH are rather long and the expected value of ENC in absence of other contribution is of the order of 200 \( e^- \).
The charge signal is transformed into a differential current output transmitted serially by each hybrid to a remote data acquisition board, where the currents are transformed into voltages by transimpedance amplifiers and then digitized by a 12 bit flash-ADC capable of digitizing the voltage difference at its input. The data boards perform several additional complex functions, like providing the power supply and bias currents necessary for the VA_RICH to be at its optima working point. In addition, the digital component of these boards provides sparsification, buffering and memory for pedestal and threshold values.

If a track crosses the LiF radiator at normal incidence, no light is emitted in the wavelength range detected by TEA, due to total internal reflection. In order to overcome this problem a novel radiator geometry has been proposed. It involves cutting the outer surface of the radiator like the teeth of a saw, and therefore is referred to as “sawtooth radiator”. A detailed simulation of several possible tooth geometries has been performed and a tooth angle of 42° was found out to be close to optimal and technically feasible.

There are several technical challenges in producing these radiators, including the ability of cutting the teeth with high precision without cleaving the material and polishing this complex surface to yield good transmission properties for the ultraviolet light. One of the goals of the test beam run described below was to measure the performance of sawtooth radiators and we were able to produce two full size pieces working with OPTOVAC in North Brookfield, Mass. The light transmission properties of these two pieces were measured relative to a plane polished sample of LiF and found to be very good.

5 Test beam results

Two completed CLEO III RICH modules were taken to Fermilab and exposed to high energy muons emerging from a beam dump. Their momentum was $\geq 100$ GeV/c. The modules were mounted on a leak tight aluminum box with the same mounting scheme planned for the modules in the final RICH barrel. One plane radiator and the two sawtooth radiators were mounted inside the box at a distance from the photodetectors equal to the one expected in the final system. Two sets of multiwire chambers were defining the $\mu$ track parameters and the trigger was provided by an array of scintillator counters. The data acquisition system was a prototype for the final CLEO system.

The beam conditions were much worse than expected: the background and particle fluxes were about two order of magnitude higher than we expect in CLEO and in addition included a significant neutron component that is going to be absent in CLEO. Data were taken corresponding to different track incidence angles and with tracks illuminating the three different radiators. For the plane radiator, we were able to configure the detector so that the photon pattern would appear only in one chamber. For the sawtooth radiator a minimum of three chambers would have been necessary to have full acceptance.

The study of this extensive data sample has been quite laborious and the full set of results is beyond the scope of this paper. The results from two typical runs will be summarized in order to illustrate the expected performance from our system: the first case will involve tracks incident at 30° to the plane radiator and the second tracks incident at 0° on a sawtooth radiator.

The fundamental quantities that we study to ascertain the expected performance of the system are the number of photons detected in each event and the angular resolution per photon. The measured distributions are compared with the predictions of a detailed Monte Carlo simulation, including information on the CH$_4$-TEA quantum efficiency as a function of wavelength, ray tracing, crystal transmission, etc.. It includes also a rudimentary model of the background, attributed to out of time tracks. The agreement between Monte Carlo and data is quite good. The average number of detected photoelectrons is about 14 after background subtraction and the angular resolution per photon is about 13.5 ± 0.2 mr.
The average number of photons, after background subtraction, is 13.5, with a geometrical acceptance of only 55% of the final system. In this case it can be seen that the expected resolution is slightly better than the one achieved. In order to estimate the particle identification power in our system, we need to combine the information provided by all the Cherenkov photons in an event. We can use the resolution on the mean Cherenkov angle per track as an estimator for the resolving power in the final system.

Table 1 shows a summary of the predicted and achieved values of these variables in the two data sets discussed in this paper and in the corresponding Monte Carlo simulation, as well as the expectations for the final system. Fig. 2 shows the measured resolution per track \( \sigma_t \) as a function of the background subtracted number of photons detected for the flat radiator and Fig. 2 shows the corresponding curve for the sawtooth radiator. The curves are fit to the parameterization \((a/\sqrt{N_{ph}})^2 + b^2\).

The data shown, although preliminary, show a good understanding of the system and give confidence that the predicted level of efficiency versus resolution will be achieved in CLEO III. An active analysis program is under way to study the additional data available.

6 Conclusions

Both the major systems for the CLEO III detectors are well under way. Test runs data support the expectations of excellent performance of both the silicon tracker and the Ring Imaging Cherenkov detector. This will lead to a quite exciting physics program expected to start in 1999.

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