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Initial Performance of the SLD Cherenkov Ring Imaging Detector System[i]

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Abstract

All of the major subsystems for the barrel Cherenkov Ring Imaging Detector (CRID) in the SLD at SLAC have now been commissioned. The CRID participated in the SLD engineering run of June–August 1991. In a cosmic ray test at the end of the run, Cherenkov rings were observed for the first time. Initial data from the CRID, including Cherenkov rings, studies of minimum ionizing particles, and data from the fiber optics calibration system are presented here.

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Introduction

The SLD barrel Cherenkov Ring Imaging Detector (CRID) system [1] is designed to allow excellent particle identification in the study of Z^0 physics at the SLAC Linear Collider (SLC). It uses a combination of liquid and gas fluorocarbon radiators to allow $\pi/K/p$ separation up to 30 GeV/c, and e/π separation up to 6 GeV/c. The Cherenkov photons are focused onto quartz drift boxes, as shown in Figure 1, where they are converted to electrons by 0.1% concentration of tetrakis(dimethylamino)ethylene (TMAE) in ethane gas. The single photoelectrons are drifted by a graded electric potential to a multiwire proportional chamber. The hit wire number, drift time and charge division measurements on 7 μm carbon fibers are used to reconstruct the Cherenkov rings.

Engineering Run Status

The CRID components and support systems [2] were commissioned and tested during the engineering run of June–August 1991. All 400 mirrors [3], 40 liquid radiator trays, drift boxes and detectors were installed a year ago. The fluid delivery systems were commissioned along with their monitoring systems [4]. Front end electronics packages [5] were installed on 22 of the 40 detectors. Lack of access to the SLD when the run began, prevented the installation of

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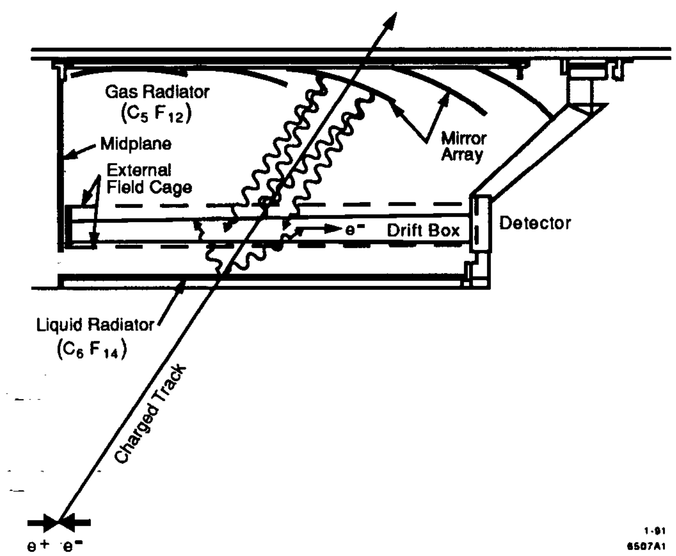

Figure 1: Quarter section of the SLD barrel CRID showing its principal components.

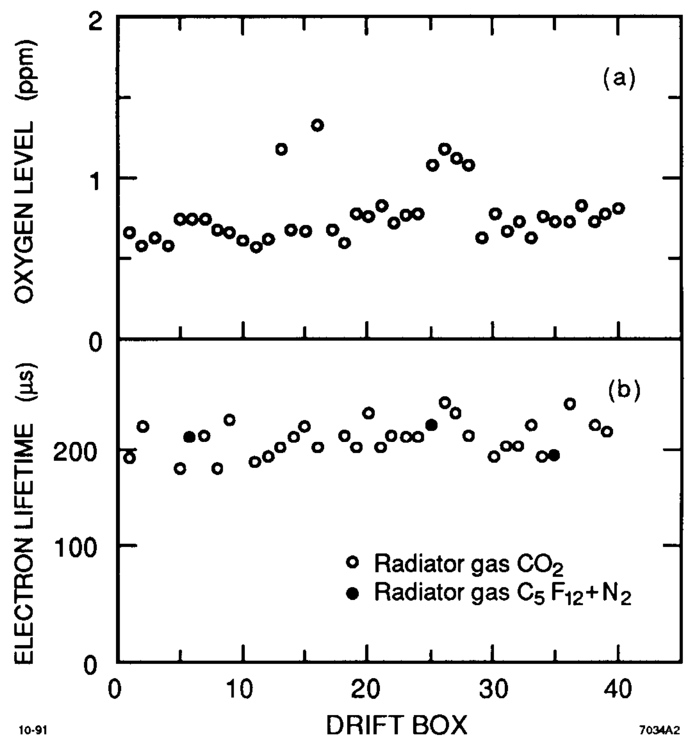

Figure 2: (a) Trace oxygen levels before the introduction of TMAE for all 40 drift box return lines. (b) Electron lifetimes as measured by a miniature ionization chamber for the return gas from all the drift boxes. The radiator gas was CO_2 for the measurements shown as open circles. The lifetime did not change when highly electronegative C_5F_{12} was introduced into the CRID vessel, as indicated by the dark circles.

the rest of electronics packages. The front end electronics, FASTBUS data acquisition modules, and software systems were debugged during the run. The fiber optics calibration system was in place and was used extensively to test the performance of the drift boxes. The temperature control and monitor system was also in place and was operated at 30°C, instead of the nominal 40°C, because thermal insulation was not completely installed to protect the SLD drift chambers.

The vessel was filled with CO_2 gas, in place of the C_5F_{12} gas radiator, to allow high voltage operation while the radiator fluid systems were being commissioned. All drift boxes and detectors [6] were tested successfully at full voltage before the run began.

The drift gas delivery system supplied CP-grade ethane after passing it through filters to remove oxygen, water vapor and other contaminants that reduce the electron lifetime or otherwise affect the CRID components. The quality of the gas was monitored on return lines from the drift boxes by measuring electron lifetimes, UV transparency, and trace oxygen and water vapor content. The oxygen content in the drift gas return lines was measured before introducing TMAE into the system. These data, shown in Figure 2(a), indicate that, for most of the drift boxes, oxygen level is about 0.7 ppm. However, there are six boxes whose oxygen levels are significantly larger than the average, indicating a small leak. That the effects were due to leaks in the return lines, was verified by varying the gas flow through those lines. It is of interest to note that the oxygen meter [7], when used to make a relative measurement, can detect oxygen leaks at the 0.3–0.5 ppm level.

The low oxygen and water vapor levels gave us enough confidence to introduce TMAE into the drift boxes. The drift gas was doped with TMAE, by bubbling the gas through 15°C liquid TMAE, and was supplied to the drift boxes in the middle of the engineering run. The nominal TMAE temperature is 27°C, but we chose to be conservative and run the system at lower temperature. Electron lifetimes were measured using a miniature ion chamber [8]. These measurements, shown in Figure 2(b), are consistent with our previous test bench results for the cleanest drift gas doped with TMAE. The lifetime did not degrade even when highly electronegative C_5F_{12} gas was introduced into the gaseous radiator volume in the later part of the run, as indicated by the dark points in Figure 2(b). Based on these measurements, it appears that the leaks detected by the oxygen meter are too small to affect the electron lifetime.

By the end of the run, the gas radiator recirculation system was commissioned. A 50-50 mixture of C_5F_{12} and N_2 gases was introduced into the CRID vessel. This gas mixture has a condensation point below room temperature, and was, therefore, safe to use while the CRID was maintained at 30°C. The homogeneity of the gas mixture was determined to be better than 1% by sonar monitoring [4].

The liquid radiator recirculation system was also commissioned at the end of the run. The quality of the liquid was monitored extensively offline by measuring its UV transparency. Six trays were then filled with C_6F_{14} liq-

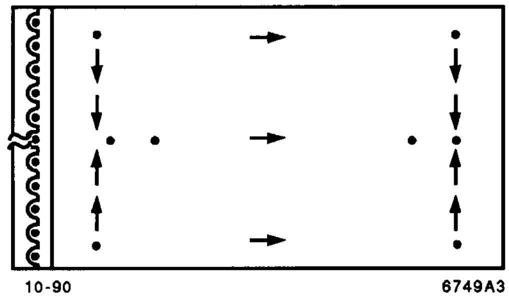

Figure 3: A schematic drawing of the placement of UV optical fibers on the drift boxes. The dots indicate fibers placed perpendicular to the quartz surface of the box. The arrows indicate the direction of the 45° plane in which the beam from the fiber is aimed.

uid. However, only a fraction of these trays were situated in front of detectors with fully operating electronics.

Early in the run, before the radiators were commissioned, charged tracks produced in e^+-e^- collisions were observed clearly, by detecting the ionization left by them in the CRID. These data demonstrated that the electronics and the data analysis programs worked adequately [5]. However, we were unable to obtain Cherenkov ring data at that time. When the radiator fluids were available, dedicated CRID tests were conducted and their results are described below.

UV Fiber Results

A UV fiber optic system [2] attached to all 40 drift boxes is used for the purpose of continuously monitoring drift velocities, measuring drift path distortions, and checking the charge division on the anode wires. In this system, a UV flashlamp illuminates a set of optical fiber bundles which transmit the UV signal to the drift boxes. The arrangement of fibers on each drift box is shown in Figure 3. There are three different orientations: eight beams are directed perpendicular to the quartz window (indicated by dots in the figure) and are used to monitor the electron drift velocity. The remaining fibers are angled at 45° with respect to the quartz window, in the planes indicated by the arrows. The four fibers closest to the detector are used to check the charge division calibration of the wires. The remaining angled fibers are used to measure drift path distortions in the depth coordinate. All fibers are used to measure distortions in the width coordinate.

The single photoelectrons produced by the light from the fibers are useful for a number of diagnostic and commissioning purposes. As soon as the TMAE dopant was introduced into the drift gas, the single electron hits were detected. The pattern of these hits, shown in Figure 4, is as expected. This fact demonstrates not only that single electrons are observed, but also that the charge division coordinate is being well reconstructed, and that there are no serious distortions in the drift paths. The data from the fibers placed at various positions along the box are used to

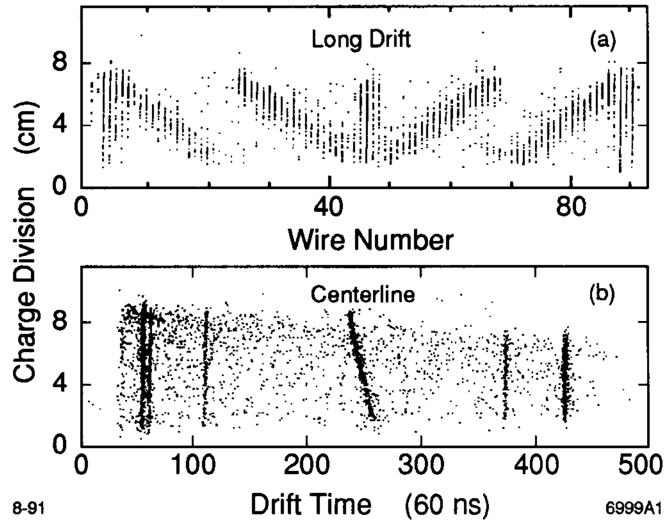

Figure 4: Representative results from UV fibers on drift boxes: (a) in a plane parallel to the detector wire plane; and (b) in a plane down the middle of the drift box.

measure the drift velocity. The drift velocity data shown in Figure 5 are better than the required 0.1% accuracy. These measurements were made with dedicated fiber runs immediately following the engineering run. Each point is based on at most the amount of data expected in one hour of SLD data running and is the average over the 17 operational drift boxes. The error bars are statistical only. The expected slow variations in drift velocity will be tracked to better than the required accuracy.

Cosmic Ray Test Results

During the cosmic ray run, when gas and liquid radiators were in place, we observed candidate Cherenkov rings. The cosmic ray muon trigger was provided by the SLD muon calorimeter, and the data were collected for the CRID and the central drift chamber. Many of the several hundred events collected were scanned individually to identify candidate Cherenkov rings, and a sample set of events was determined. These events were reanalyzed offline with full tracking and CRID analysis.

The liquid ring data sample is rather limited because triggered cosmic rays passed through only one filled liquid radiator tray. The CRID offline analysis program extrapolates the reconstructed drift chamber tracks to the middle of the liquid radiator tray. For each CRID hit, the program then computes the polar angles with respect to the drift chamber track direction, so that a Cherenkov photon emitted by the charged particle would make a hit at the observed point. These reconstructed Cherenkov photon angles ($\theta_C \cos\phi_C$, $\theta_C \sin\phi_C$) are plotted in Figure 6 for one such event. The resolution of the angle θ_C was determined by using the complete data set to be ~25 mrad, and 2σ contours of the expected Cherenkov angle are also plotted on Figure 6. Note that in this particular cosmic ray event

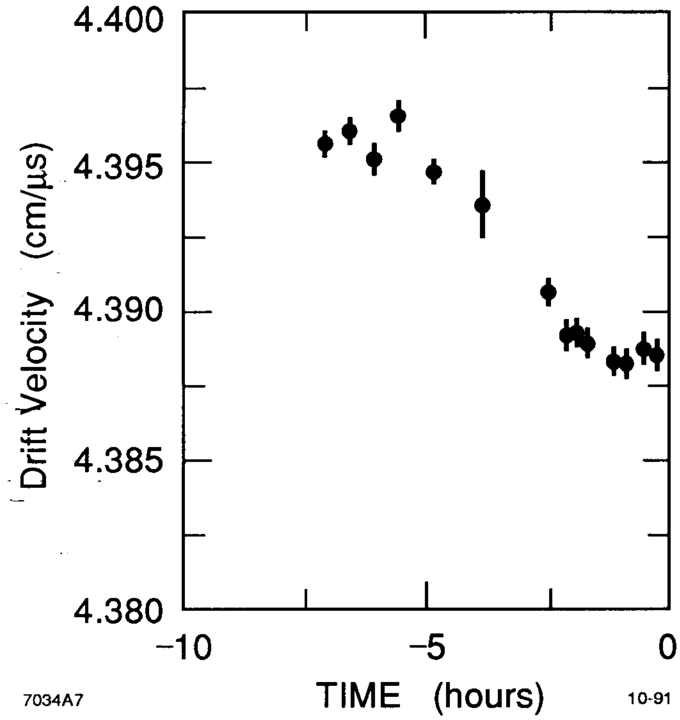

Figure 5: Measured drift velocity, averaged over 17 working drift boxes, as a function of time, demonstrating the ability to measure and calibrate this quantity with the fiber optic system. An overall systematic error of ± 0.002 cm/μs is not shown.

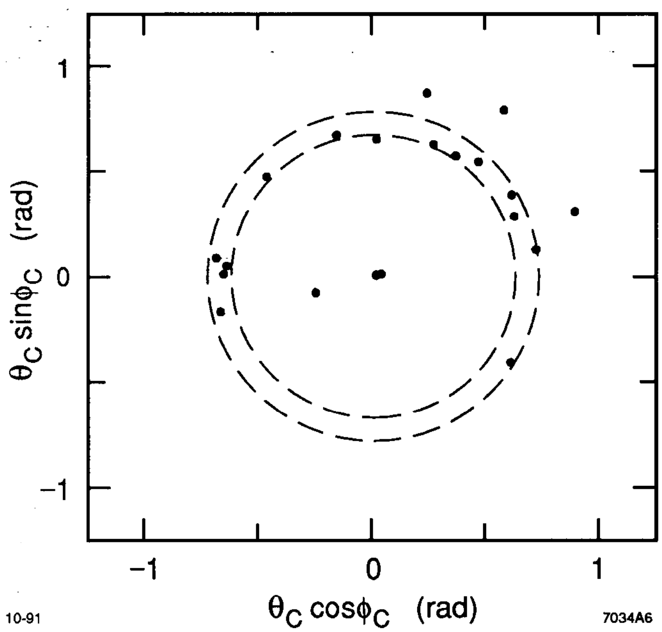

Figure 6: Reconstructed liquid Cherenkov angles for a cosmic ray event. The points near the origin are hits associated with the minimum ionization particle signal from the muon. The dotted lines represent the $\pm 2\sigma$ expected region for Cherenkov photons. There is very little background. Two of the three hits in the upper right corner are consistent with radiation from the quartz window on the liquid radiator tray.

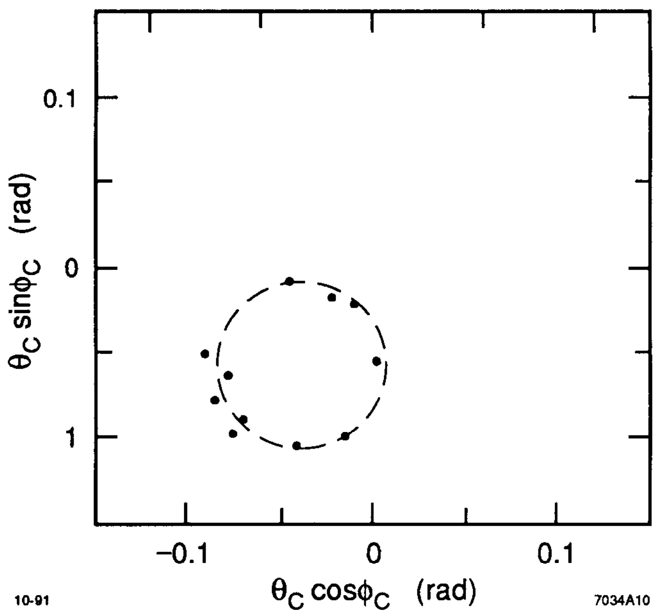

Figure 7: Reconstructed gas Cherenkov angles for a cosmic ray event along with a ring having the expected radius of 45 mrad. The mirror alignment is still under study and is expected to account for the shift in the ring from the origin.

the muon track crossed the liquid radiator tray perpendicular to the quartz window. The gap in the Cherenkov ring is due to the gap between the two drift boxes. In a typical e^+-e^- collision event, tracks originate from the interaction point, and cross the tray at an angle. For these more typical tracks, there is a cutoff in the ϕ_C angle due to total internal reflection.

We have also identified candidate gas rings from this data sample. The reconstructed Cherenkov angles from one such gas ring are plotted in Figure 7. The expected θ_C is 45 mrad. A circle of this radius centered in the middle of the hits is also shown in Figure 7. The mirror alignment is still under study and is expected to account for the shift in the ring from the origin. We are also studying the alignment of the CRID system with the central drift chamber using these cosmic ray data.

CONCLUSION

The SLD Engineering run and the ensuing dedicated CRID test runs have demonstrated that the system behaves as expected. We have been able to track particles using ionization in the drift boxes, and reconstruct single electron coordinates very well. We have also reconstructed Cherenkov rings in the cosmic ray test. The runs have also enabled debugging of this complex system. We are now in the process of completing the installation of the remaining electronics packages, and refining the data acquisition and analysis software. We expect to have a complete CRID for the next SLD data run.

REFERENCES

[1] "SLD Design Report," SLAC–273, UC–43D (1984), and revisions.

[2] P. Antilogus et al., "Component and System Tests of the SLD Cherenkov Ring Imaging Detector," SLAC–PUB–5365, contributed to *1990 IEEE Nucl. Sci. Symp., Arlington, VA* (1991).

[3] K. Abe et al., "Production of 400 Mirrors with High UV Reflectivity for use in the SLD Cherenkov Ring Imaging Detector," *Nucl. Instr. and Meth.* **A300** (1991) 501.

[4] P. Antilogus et al., "Monitor and Control Systems for the SLD Cherenkov Ring Imaging Detector," *Nucl. Instr. and Meth.* **A293** (1990) 136.

[5] P. Antilogus et al., "Cherenkov Ring Imaging Detector Front-End Electronics," *IEEE Trans. Nucl. Sci.* **NS–38** (1991) 408; and K. Abe et al., "Performance of the Front-End Electronics and Data Acquisition for the SLD Cherenkov Ring Imaging Detector," contribution to this conference.

[6] K. Abe et al., "Electrostatic Design of the Barrel CRID and Associated Measurements, SLAC–PUB–5214, contributed to *Vth Intn'l. Conf. on Instrum. for Colliding Beam Physics, Novosibirsk, USSR* (1990).

[7] Oxygen Micro Fuel Cell made by Teledyne Analytical Instruments, 16830 Chestnut Street, City of Industry, CA 91748.

[8] M. Cavalli-Sforza, Electron Lifetime Measurements in the Disaster Monitor, CRID Memo 15 (1986).