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THE FIRST RESULTS FROM THE CRID DETECTOR AT SLD*

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Abstract

We report first results from the initial physics run of the Cherenkov Ring Imaging Detector (CRID) in the SLD experiment at the SLC. We describe the experimental conditions, show liquid and gas rings, report the number of photoelectrons per ring, and comment on resolution.

INTRODUCTION

A large Cherenkov Ring Imaging Detector (CRID) is now operating in the SLD experiment. We restrict our discussion to the barrel CRID. The end cap CRID system is completed and is presently being commissioned. The barrel CRID provides particle identification over 70% of the solid angle. By making use of both liquid and gaseous radiators, π/K/p separation will be possible up to about 30 GeV/c, and e/π separation up to about 6 GeV/c.

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The CRID detector was commissioned in 1991 during the SLC engineering run. The results reported here are based on the first physics run with 11,000 polarized Zs in SLD. The run ended in September 1992.

Figure 1 shows the geometry of the CRID. It includes 40 TPCs, 40 liquid radiator trays containing a C_6F_{14} liquid, a vessel containing a 70% C_5F_{12}+30% N_2 gas radiator, and a system of 400 mirrors. The TPC gas was C_2H_6+TMAE (~0.1%). The TMAE bubbler temperature was 23.5°C and the system temperature was 30-32°C during the physics run.

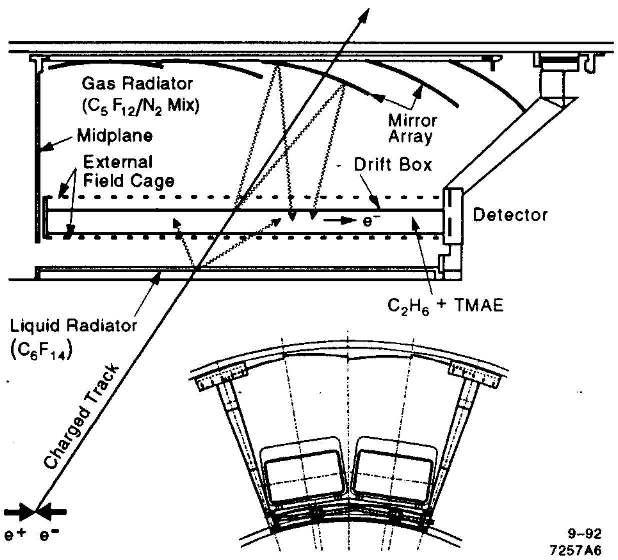

Figure 1. Schematic of the SLD barrel CRID

The expected Cherenkov angles are 2.95° and 38.5° (for a $\beta = 1$ particle) with expected resolutions 4-5 and 12-15 mrad for gas and liquid rings respectively. The Cherenkov photons enter a 1.2 m long TPC, which has quartz sheets facing the mirrors and the liquid radiators, and photo-ionize the TMAE molecules. The photoelectron drifts to a wire chamber where its position is reconstructed using a combination of drift time (TPC length), wire address (TPC width), and charge division (TPC depth) with a precision of 1 x 1 x 1.5 mm.

The concept of CRID/RICH detectors was pioneered by T. Ypsilantis and J. Seguinot.[1] References 2-23 show a list of publications describing the history of the development of the CRID hardware since the initial SLD design report in 1984.[20] The SLD CRID[2-23] is similar in many aspects to the DELPHI RICH.[24] Both have pioneered single electron detection on a very large scale in a solenoidal geometry and must cope with the long term effects of TMAE on the detector materials, and the long term gas and liquid purity issues on a large scale. The CRID wire chamber detector is the first device to use charge division on a single electron signal, and to incorporate the possibility of removal of wire aging deposits by heating the 7 micron carbon anode wires. Despite their fragility, we have lost only 3 wires out of 3720 since the beginning of the commissioning.

OPERATIONAL EXPERIENCE

Not only does TMAE[25] photo-ionize in the presence of U.V. Cherenkov photons, but it also is sensitive to unwanted U.V. photons from various atomic lines excited in the avalanche process, resulting in secondary photo-electron emissions which cause after-pulses. In our case, the dominant excitations are three C*(carbon) lines (in our sensitive acceptance): 1931 Å, 1657 Å and 1561 Å.[26] However, since these photons are also absorbed by the ethane gas, causing predominantly molecular excitations, TMAE is sensitive only to the first line at a significant distance from the anode wire. To limit the rate of the after-pulses in the TPC active volume we have equipped the single electron detector with "blinds".[7,16] Based on R&D tests,[7] the observed rate of after-pulses is less than 1% with the blinding electrodes, but about 7% without blinds. Avalanche U.V. photons can also initiate chamber breakdown.[27] Based on one year of experience, the CRID detectors are behaving stably even in the presence of occasional relatively large background bursts (see below).

In our early R&D tests we discovered substantial TMAE wire aging – about a 50% gain drop for a charge dose of 0.2 mC/cm of wire length.[21] We estimate that we have accumulated about one-tenth of this dose to date and we do not yet see any significant effect in wire gain. At this conference, the Omega experiment has reported a large rate of wire aging with TMAE under real physics conditions,[28] which is consistent with our earlier R&D test data.[21] We are taking the TMAE aging seriously and have incorporated an automatic high voltage control scheme which automatically reduces the gain when the cathode current exceeds a certain threshold. In addition, we do have the capability to remove wire deposits by sending a 10 mA current into each anode wire but have not yet found it necessary to do so.[16,21] Wire aging, as discussed above, is caused by the presence of a thin film deposited on the anode wire surface. However, there is another possible aging effect caused by an insulating deposit on the cathode wire surface. In this case, it is initiated by background which produces a positive ion buildup on an insulating deposit present on the cathode wire, which subsequently causes electron emission, and at the very end a standing current – the so-called Malter current.[29] We have one detector which developed such a current after long exposure to TMAE. The current is observed only in the presence of gating (when gating is on, the positive ions travel toward the gating wire plane). If TMAE is removed from the gas this problem goes away. The Malter effect is a problem in principle for the "CRID type" of detector operating with TMAE, because unlike all other wire detectors, we cannot add any substantial amount of water to our gas (for example, the SLD drift chamber has 0.4% of water in the gas mixture). So far we have opted to run without the gating and we will investigate this particular detector during the shutdown.

Charge division corrects for the photon depth coordinate in the TPC; i.e., it allows correction for a parallax error. Without this correction the Cherenkov angle resolution broadens by about a factor of two.[19] In the final CRID system the charge division error obtained with an average wire gain of about $2x10^5$ is expected to be about 1.5% of wire length. It is somewhat worse than in our earlier R&D tests which measured 0.9%;[12] the degradation is caused by noise in the production amplifiers. However, the performance is sufficient to correct for the parallax error.

Each TPC has a system of 19 silica fibers,[9] each equipped with a collimator to shape a photon beam as it enters the TPC. We record fiber data continuously while taking physics data, and use these as fiducial marks to monitor the drift velocity to about 0.1% accuracy, charge division offsets, drift distortions due to the radial magnetic field component, distortions due to positive ions present in the TPC volume, and single electron pulse height spectra. These data are extremely important for achievement of the required resolution.

The TPC detectors are sensitive to distortions due to positive ions. In our earlier R&D tests[4] we have observed distortions of several mm for positive ion densities ~$5x10^5$ ions per cm^3 without the presence of gating, and no distortion with the gating on under the same background conditions. During the physics run we have seen no evidence for distortions due to positive ions, even without the gating.

Because of the large scale of the system, *the maintenance of fluid purity is one of the hardest problems in the CRID.*

The barrel TPC gas consists of C_2H_6+ TMAE mixture. The data presented in this paper were obtained by bubbling the C_2H_6 gas through liquid TMAE at 23.5°C resulting in about 0.1% of TMAE by volume. The gas flow was typically 7 l/m; i.e., each TPC volume was exchanged every 4-5 hours. The ethane gas[31] was purified by a combination of 13X Molecular sieve[32] and Oxisorb.[33] Typical oxygen levels at the exit of the TPCs were less than 0.5 ppm and the water level was below 5 ppm. TMAE was purified at SLAC using the following steps: (a) washing 3-4 times in distilled water; (b) filtering through a column of 3A, 4A molecular sieves and silica gel;[35] and (c) pumping on it 4-12 hours at a pressure of 20-80 torr. We found a substantial level of sulfur in our ethane supply. One ethane gas trailer had 0.5 ppm, and the second one 3 ppm. Sulfur is very reactive with copper, silver gaskets, etc., even at these low concentrations. To remove the sulfur we added a nickel based absorber.[34] However, the nickel cartridge outgassed a substantial amount of oxygen while in use, and it was necessary to add another Oxisorb to have double protection.

The presented data used 70% C_5F_{12}+30% N_2 as the gas radiator mixture.[36] The gas flow was typically 30-40 l/m; i.e. the vessel volume of about 13,000 liters was exchanged every 6-7 hours. The oxygen and water levels in the gas radiator are typically less than 5 and 50 ppm respectively, which causes a negligible loss of Cherenkov photons in our geometry. Other impurities were removed by a recirculation system in two steps: the first step was a simple distillation of the C_5F_{12} by allowing it to condense at a temperature of about -80°C, and then evaporating it again at a temperature of 30°C; the second step circulated the C_5F_{12} liquid through purifiers placed in the following sequence: silica gel, elemental copper[37] and Oxisorb (latest addition). We found that the liquid phase purification was more efficient than cleaning in the gas phase. We monitor the mixture in the vessel using a sonar technique[23] and have not observed any stratification.

The liquid radiators contain C_6F_{14},[38] which is first de-oxygenated at the beginning of the run by bubbling N_2 gas through it. During the run, oxygen and other impurities, such as outgassing from DP-190 epoxy,[4] were removed by pumping the liquid continuously through an Oxisorb.

Figure 2 shows our expected detection efficiency as a function of U.V. photon energy for (a) gas rings and (b) liquid rings. Many factors go into the calculation of the efficiency. For example, Figure 2(a) shows the measured U.V. transmission of a typical 3.2 mm thick fused silica quartz window[39] used in construction of the TPCs,[12] the measured mirror reflectance,[6] the measured transmission of the radiator gas scaled to a path length of 80 cm, and the measured TMAE quantum efficiency.[28] To get the final detection efficiency, we included present approximate estimates for the various correction factors such as chamber efficiency, electron lifetime, absorption in TMAE, absorption in field cage wires, etc. The resulting estimated N_0 for gas rings is 55-65 cm^{-1}. Similarly, Figure 2(b) shows the detection efficiency for liquid rings; the estimated N_0 is 45-55 cm^{-1}. The measured numbers of photoelectrons are consistent with these esti-

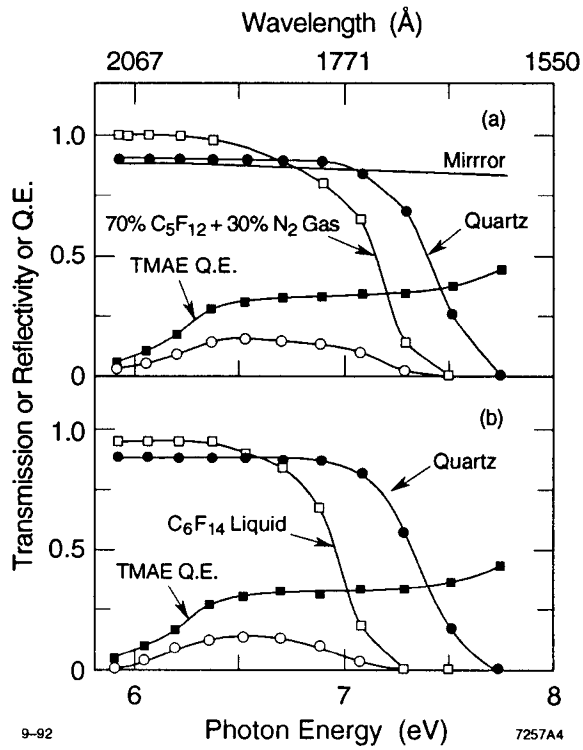

Figure 2. The expected efficiency (open circles) for Cherenkov photons from (a) gas rings; (b) liquid rings; the most important contributions to the total efficiency are also shown: 3.2 mm of silica quartz for gas rings and 4.1mm for liquid rings; 1 cm of liquid C_6F_{14}; 80 cm of the 70%C_5F_{12}+30%N_2 gas mixture.

mates (the number depends on track orientation).

In future, we expect further improvements because we have increased the TMAE bubbler temperature to 25°C, the gas radiator mix to 75% C_5F_{12}+25% N_2 and the system temperature to 34°C at the end of the run. We have run lower temperature compared to the original design because of safety concerns related to the SLD central drift chamber's aluminum wires which could overtension in case of a thermal accident.

EXPERIMENTAL RESULTS

The CRID analysis is just beginning, and many corrections are not yet fully understood; such as, drift velocity variation, charge division offsets, distortions along the edges of the TPC's, distortions due to the radial component of the magnetic field, mirror alignment, and TPC with respect to the drift chamber. Therefore, in case of gas rings we present results using an internal fit to align the ring centers. Also, spurious hits caused by cross-talk or nonlinear response of the amplifiers to the very large charges caused by charged particles traversing the TPC cannot yet be satisfactorily cut out. Nevertheless, we see good performance for both radiator systems.

Figures 3(a), (b) and (c) show integrated gas rings for cosmic ray muons, Bhabha electrons and tracks from hadronic events respectively, with momenta higher than 7 GeV/c. Figures 4(a) and (b) show the measured Cherenkov angle resolution and the number of photoelectrons per ring in the case of cosmic ray muons. The results in Bhabhas and hadronic events are very similar. The measured Cherenkov angle resolution of 4 mrad is close to the expected resolution. The number of photoelectrons is typically 10, consistent with the expectation for our particular gas radiator mixture. Notice in Figure 1 that the mirror optics were designed so that gas rings are well separated from the dE/dx deposit, thus reducing unwanted background.

Figures 5 and 6 show integrated liquid rings for the cosmic ray muons and Bhabha electrons. The average number of photoelectrons per full liquid ring (as in Figure 5(a)) is about 17 for cosmic ray muons, and 11 in Bhabha events (as in Figure 6). The resolution in Cherenkov angle is still a factor two higher than expected, mainly because of the alignment issues mentioned above

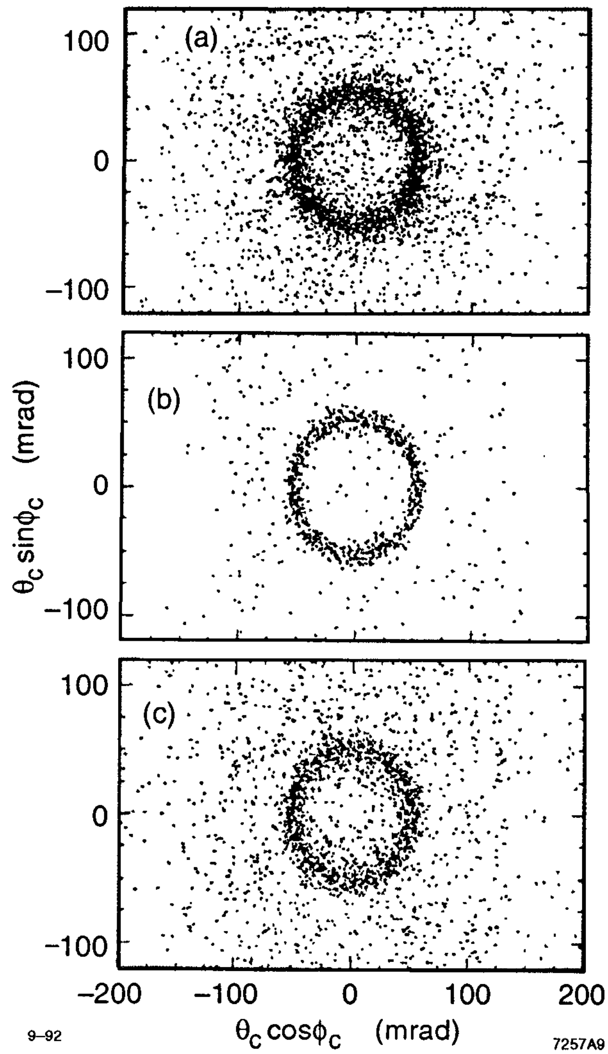

Figure 3. (a) Integrated gas rings observed in cosmic rays; (b) Bhabhas; and (c) hadronic events for p>7GeV/c.

CONCLUSION

The CRID hardware performs well with good efficiency for U.V. photons and good internal TPC resolution. However, it will still take a nontrivial amount of time to align the system and understand other software corrections before the CRID is fully functional as a particle identification device in inclusive Z events.

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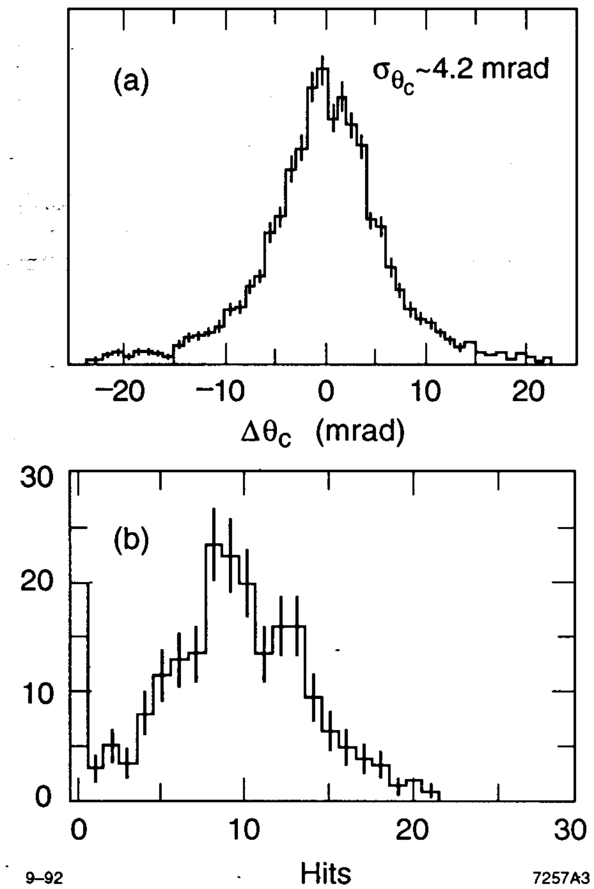

Figure 4. (a) Resolution in Cherenkov angle; and (b) number of photo-electrons per gas ring from cosmic ray muons.

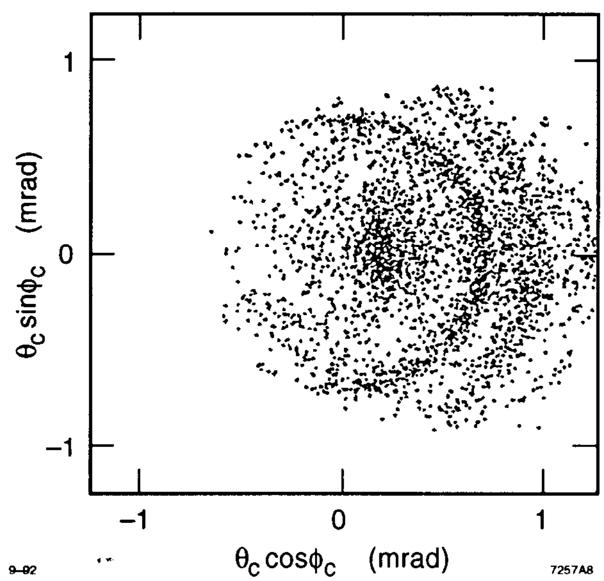

Figure 6. Integrated liquid rings observed in Bhabha tracks.

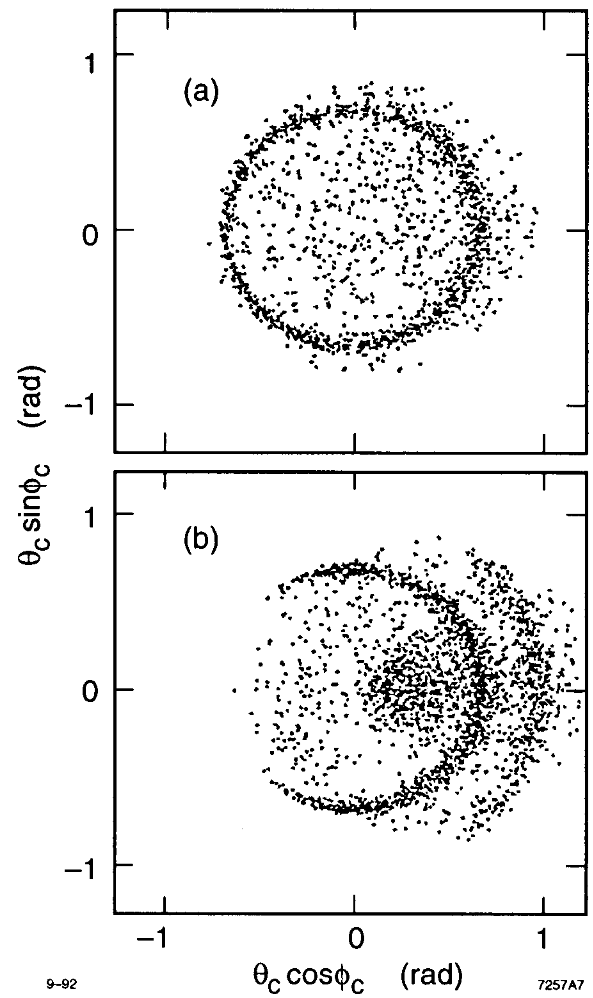

Figure 5. Integrated liquid rings observed in cosmic rays for tracks with (a) a full ring; (b) a partial ring.

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