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Operational Experience with a Large Detector System using Silicon Strip Detectors with Double Sided Readout

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Abstract

A large system of silicon strip detectors with double sided readout has been successfully commissioned over the course of the last year at the e^+e^- collider LEP. The readout of this 73,728 channel system is performed with custom designed VLSI charge sensitive amplifier chips (CAMEX64A). An overall point resolution of 12 µm on both sides has been acheived for the complete system. The most important difficulties during the run were beam losses into the detector, and a chemical agent deposited onto the electronics; however, the damage from these sources was understood and brought under control. This and other results of the 1991 data-taking run are described with special emphasis on the operational experience.

The ALEPH microvertex detector (VDET) is the first double sided silicon microstrip detector to be installed in a colliding beam experiment. It was operated successfully from April to November of 1991 in the ALEPH experiment at LEP, during which time some 320,000 decays of the Z^0 boson were observed and recorded. In this note we will give a short description of the VDET, then describe its performance in 1991, the alignment of the detector, and our experience operating the detector in a colliding beam experiment.

The VDET (figure 1) consists of two concentric layers of silicon microstrip wafers, their ceramic support structures, and their readout electronics, fastened to a light weight graphite frame. The radius of the inner layer is 6.3 cm, while that of the outer layer is 10.7 cm. The full system contains about 0.25 $m^2$of silicon and 73,728 channels. The VDET is installed around the beam pipe in ALEPH where its high precision coordinate measurement complements the tracking of two other tracking detectors, the Inner Tracking Chamber (ITC, a conventional drift chamber between radii of 13 and 29 cm), and a Time Projection Chamber (TPC, between radii of 31 and 180 cm)[1]. Two thirds of the channels give position information along the beam direction (the z direction) and one third give position information around the beam direction (the ϕ direction).

The basic mechanical unit of the microvertex detector[2] is called a "face", nine of which form the inner layer and 15 of which form the outer layer. A face is four silicon wafers glued to a ceramic holding structure which provides the mechanical support for the wafers and also serves as a substrate for hybrid circuitry. Two wafers are connected electrically to form the basic electronic unit, a "module", so that one face contains two modules. The front-end electronics for the ϕ readout are located at either end of the ceramic support; those for the z readout are located under the ceramic support.

The microstrip detectors (figure 2) are 5.12 cm x 5.12 cm x 300 µm wafers of high-resistivity silicon into which have been implanted p^+strips, at a pitch of 25 µm, on one side (the ϕ side). On the opposite side (the z side) and oriented in the orthogonal direction, n^+strips have been implanted at a pitch of 50 µm. The n^+strips on the z side alternate with p^+strips whose purpose is to interrupt the surface charge at the $Si\text{-}SiO_2$ interface, which would otherwise short-circuit the n^+ strips and spoil the position sensitivity of the device[3].

Guard rings on both the ϕ and the z sides are used to bias the detector[4], on the ϕ side via the punch-through effect, and on the z side via an interface charge which is still present in the channel between the p^+strips and which forms a resistive connection between the guard ring and the n^+ strips[5]. The depletion voltages vary over the wafers used in the detector between 16 and 65 volts.

On the ϕ side every fourth strip is read out, while on the z side every second n^+strip is read out, so that on either side the readout pitch is 100 µm. Every strip which is read out is capacitively coupled to a charge-sensitive CAMEX64A chip[6] through VLSI AC coupling chips whose capacitors have oxide layers of 64 nm. The CAMEX chip multiplexes the signals 64:1, then 16 CAMEX outputs are shifted sequentially to the output of a line driver. The six line drivers from a module are again multiplexed 6:1 outside of the detector, then digitized in one half of a Sirocco IV module[7], which integrates a flash ADC and a DSP for fast common-mode subtraction, pedestal suppression, and pedestal following.

The VDET suffers only a modest radiation dose in the ALEPH environment. Approximately 20 rads per month was measured last year in its vicinity. Nearly all of this occurred in abnormal incidents in which the LEP beam was spilled into ALEPH. The VDET is thought to be radiation hard to about 20 Krad[8].

The VDET dissipates 60W, which is evacuated by forcing air through the cylindrical cavity containing it. It is inaccessible during physics runs, so interventions to diagnose or cure problems are limited to about once per year. The proximity of this detector to sensitive preamplifiers of gas tracking chambers has led to pickup of noisy VDET TTL-level control signals, a problem which could only be cured by carefully adjusting the position of the cables to the VDET.

Figure 3 shows a decay of the Z^0 to a pair of τ leptons in ALEPH. The helical tracks shown there are found in the ITC and TPC. One can estimate the efficiency of the VDET by extrapolating these to the detector, opening a window around the extrapolated track, and looking for VDET hits there. The overall efficiency is 90%. Contributions to the inefficiency include one module that was fully inoperational due to a single bad wire bond, "pinholes" caused by sudden beam loss in the detector, and line driver chips which died slowly over the course of the 1991 run. The latter two problems will be discussed in more detail below.

Local defects in the silicon can cause noisy strips. Neighboring strips may also become noisy due to capacitive coupling. Figure 4 shows the typical noise profile of a module. With the exception of abnormally noisy channels, the noise varies little from channel to channel. About 0.6% of the strips are suppressed due to excessive noise. The most probable channel noise for the entire detector is 31 counts. The energy loss distribution (corrected to normal incidence by dividing the ratio of path length to wafer thickness) fits well to a Landau distribution convolved with a gaussian, and peaks at 553 counts. The signal to noise ratio is 18:1 and contributes negligibly to the detector resolution.

To align the vertex detector, we cannot just minimize VDET residuals with respect to tracks found in the ITC and TPC without passing on the systematic errors inherent to these detectors to the vertex detector. Instead the VDET alignment procedure is based on internal consistency.

The alignment procedure[9] is iterative. In the first step, the VDET wafer positions are measured with a microscope, giving an accuracy of 2 μm in the plane and 10 μm perpendicular to the plane of the wafer. In the second step, 20,000 hadronic decays of Z^0s and 4000 $\mu^+\mu^-$ events are used to find the positional and rotational deviations of the wafers from their measured positions. In this procedure, double-overlap regions (regions in which a single track passes through two wafers in the same layer) are crucial. About 5% of tracks within the VDET acceptance fall into double-overlap region. Triple overlap tracks (tracks passing through a double overlap region and an independent wafer) are also very helpful, because for such tracks the position and direction is highly constrained from two of the wafers, and a residual can be calculated for the third. The aligned vertex detector is then used to help re-align the outer tracking, and afterwards the VDET re-aligns in a final iteration to insure consistency with the outer tracking.

The alignment has a statistical uncertainty of 3μm on the ϕ side and 8μm on the z side. The systematic uncertainties are estimated to be 4μm on the ϕ side and 8μm on the z side. The resolution of the aligned VDET can be checked by studying the residuals of hits found in a wafer with respect to tracks whose position, angle, and curvature are measured in the outer tracking plus two independent VDET wafers. At normal incidence a resolution of 12m in both ϕ and z is acheived. This increases at larger incidence angles.

For dimuon events, the missed distance between the two muon tracks has a measurement dispersion of 21μm in ϕ and 41μm in z, when the muon energy is constrained to the beam energy. For dimuon events whose tracks are not constrained in this way, the measurement dispersion is 35μm in ϕ and 41μm in z. This implies an impact parameter resolution of 25μm in ϕ and 29μm in z, at normal incidence.

Two major unforeseen problems were successfully dealt with during the 1991 run. The first of these was sudden beam losses into ALEPH. Synchrotron radiation from the beam losses impaired about 7% of the electronics channels (mainly on the z-side) before a fix was found to recover these channels. The damage occurred in four separate incidents, with the total radiation dose estimated at less than 10 rads in each incident. Because of the small dose involved, this clearly is unrelated to classical radiation damage; instead we call it "illumination damage". The hypothesis for the damage is illustrated in figure 5. First, a burst of ionizing radiation (rates of ~ 2 Mrad/hr for as short a period of time as 1 msec) causes current to flow in the detector, increasing the voltage across the AC-coupling capacitors C_{ac}, eventually breaking down a fraction of them. Fewer breakdowns occur to coupling capacitors C_{ac}' on the ϕ side because diode-like biasing limits the voltage across these capacitors. The effect of the damage is a current flowing into the CAMEX charge integrating amplifier during the integration period for each event, which eventually saturates the CAMEX channel. Negative feedback ceases at saturation and a large voltage variation appears on the n^+strip.This voltage variation saturates typically 12 neighboring strips via capacitive coupling. The cure for this problem is to change the operating voltage (V_{HG} in figure 5) of the CAMEX chips in order to equalize the voltages between the n^+ strip and the CAMEX input, thus minimizing the current into the CAMEX . This recovers some or all of the broken channels, and was done without removing the detector. After this fix, only 0.7% of the strips in the detector remain inactive as a result of illumination.

The second problem was a slow death of the line driver chips (1 line driver=256 strips). By the end of the run a total of 8 line drivers had died, mostly on the ϕ side of one half of the VDET, both inner and outer layers. Our uncertainty about the causes of line driver death was the strongest reason for removing the detector at the end of the 1991 running period.

We discovered that the dead line drivers were coated with a liquid residue. A distinct wind-pattern could be seen on the chips, indicating the residue had been airborne and had come from the direction of Kapton foils used to transmit signals between the module and connectors on the mounting frame. The Kapton foils themselves were examined under a microscope. On some modules a two component epoxy was used to protect the delicate wire bonds connecting the foils to the module. We found liquid-filled bubbles in the epoxy, some of which had risen to the surface of the epoxy and burst. The air cooling carried them onto the detector (on one side, where the damage occurred), and off of the detector (on the side where no damage occurred). At this time it is not understood how the liquid damaged the passivated line driver chips. The affected modules are now replaced in the 1992 VDET.

In summary, the ALEPH vertex detector ran with a resolution of 12μm after alignment, with 90% efficiency within its acceptance, and with 7% of its channels inactive for a variety of reasons. In 1992 the detector is reinstalled after repairing many of the problems. The repairs should stabilize the number of inactive channels at about 2%. We believe that this experience shows that double sided silicon microstrip detectors have advanced beyond the stage of experimental devices and are now practical to build and operate on large scales[10].

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10. Other colliding beam experiments are now planning to install double sided silicon microstrip detectors. For a review, see A. Schwarz, to be published in the Proceedings for "B Factories: The State of the Art in Accelerators, Detectors, and Physics", Stanford, California April 6-10, 1992

Figure Captions

1. The ALEPH microvertex detector, two layers of double sided microstrip detectors mounted onto a graphite holding frame. Kapton foils carry the signals between the end of the holding frame and the microstrip detectors.

2. Design of the ALEPH microvertex detector wafers.

3. A decay of the Z^0 boson into a pair of τ leptons, one decaying in a single-prong mode and the other in a three-prong mode. On the left is a distorted view of ITC, TPC and VDET which emphasizes the inner region. On the upper right is an undistorted x-y view of the VDET showing associated hits and a noise hit. On the lower right is the same in an undistorted r-z view.

4. The rms strip noise on a typical module, in units of ADC counts after gain correction. Top: in r-ϕ. Bottom: in z.

5. Electrical equivalent of the biasing structures and the readout electronics. Capacitor C_{ac} breaks down in beam loss incidents.

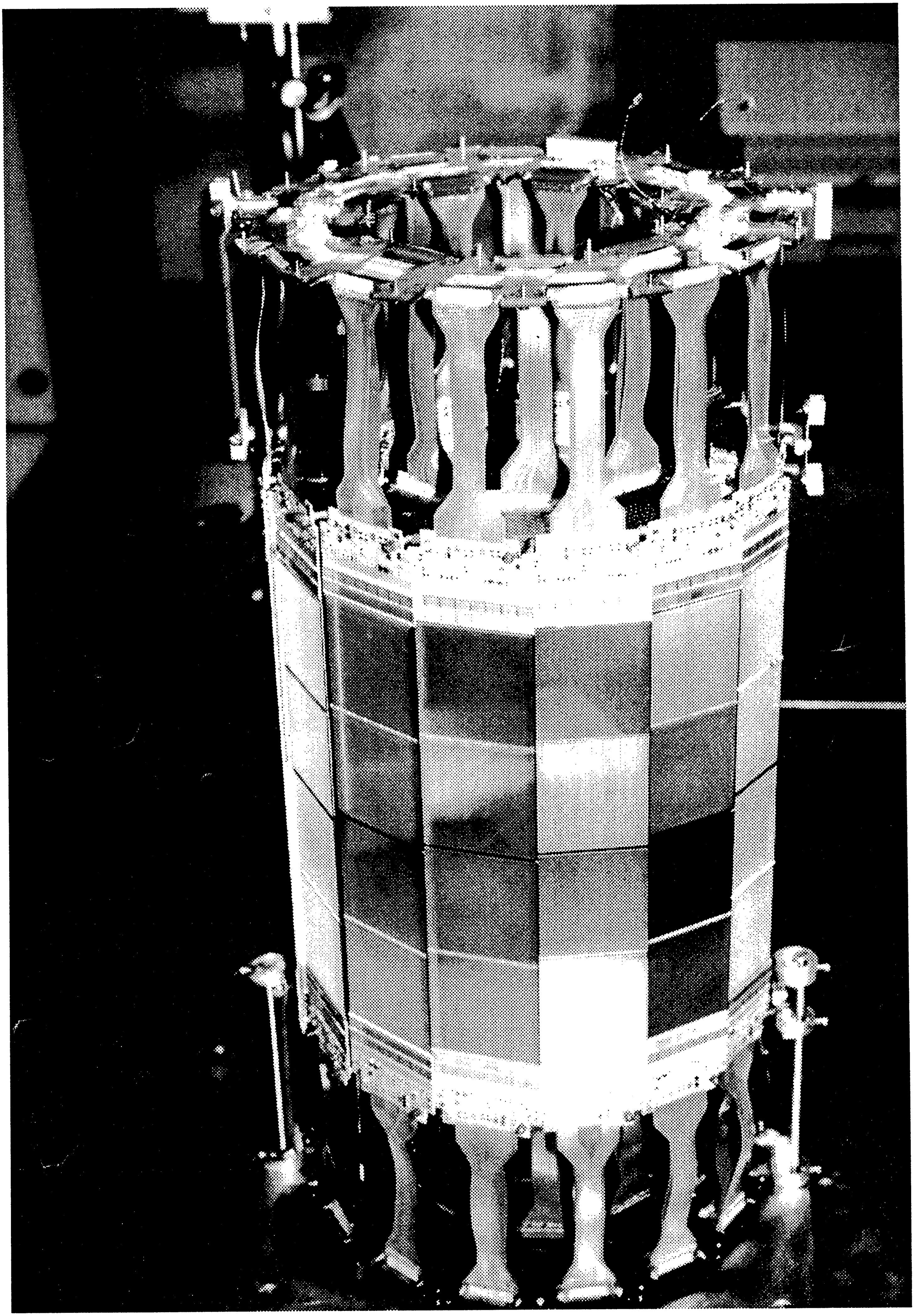


Figure 1

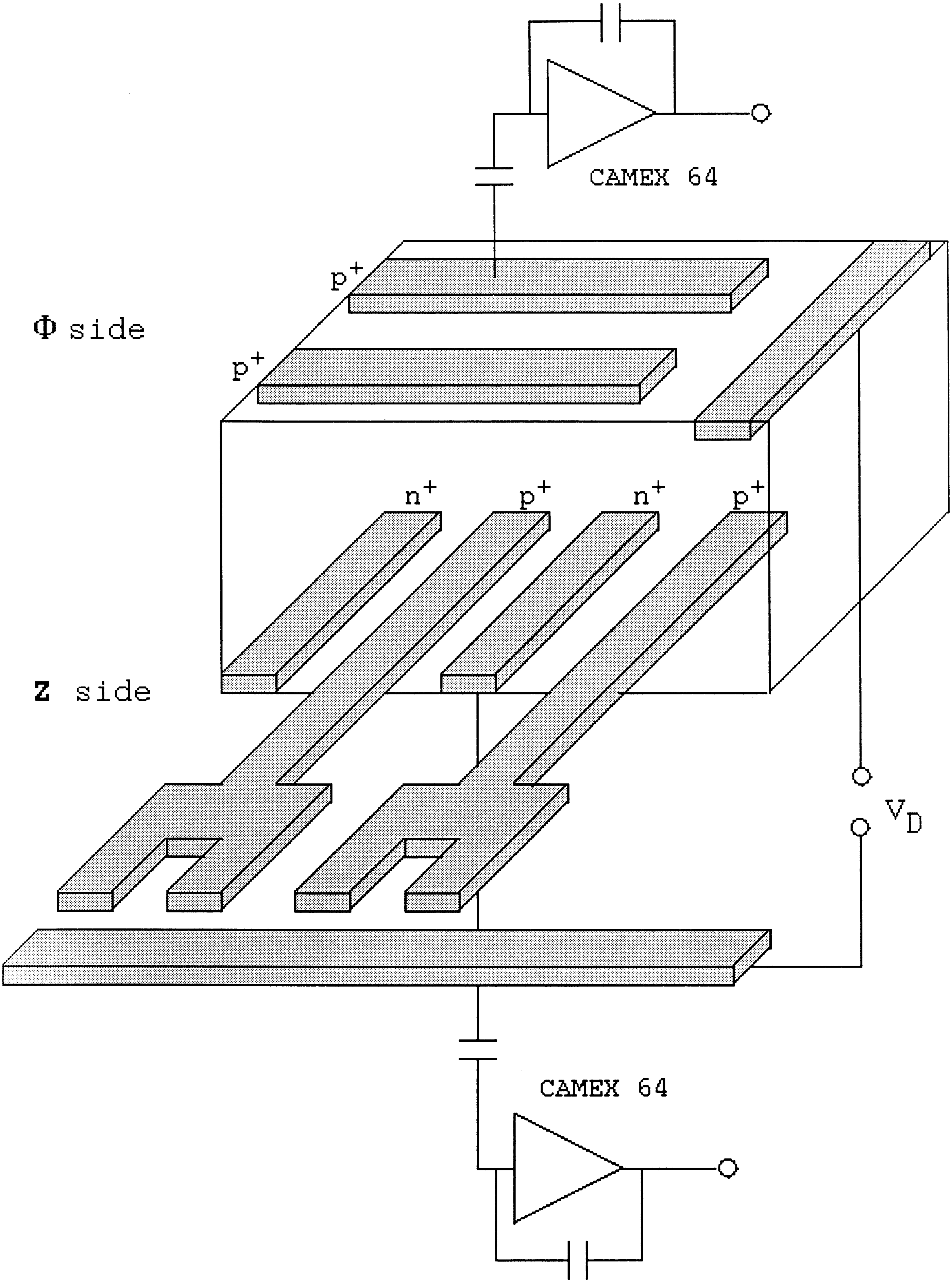
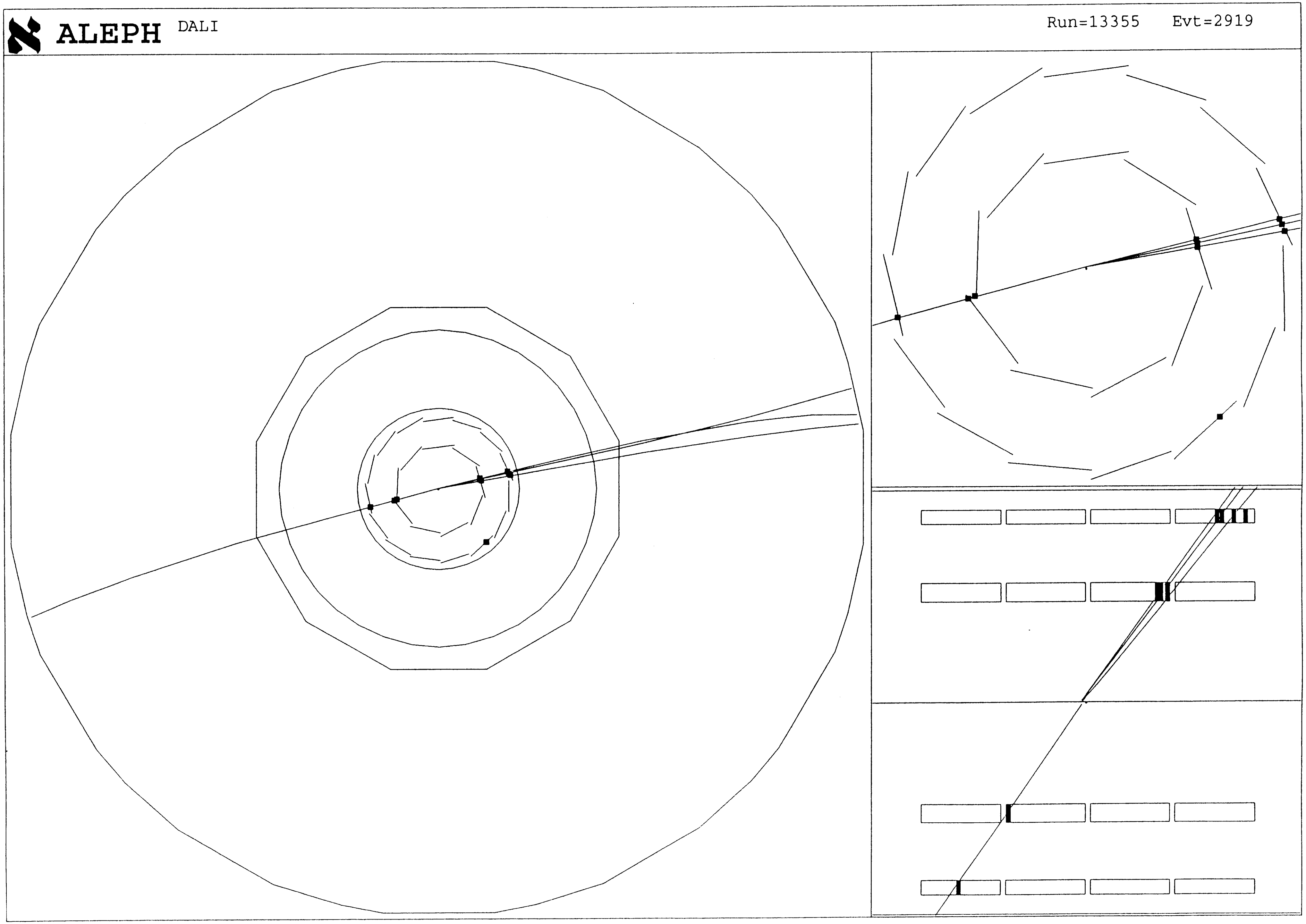
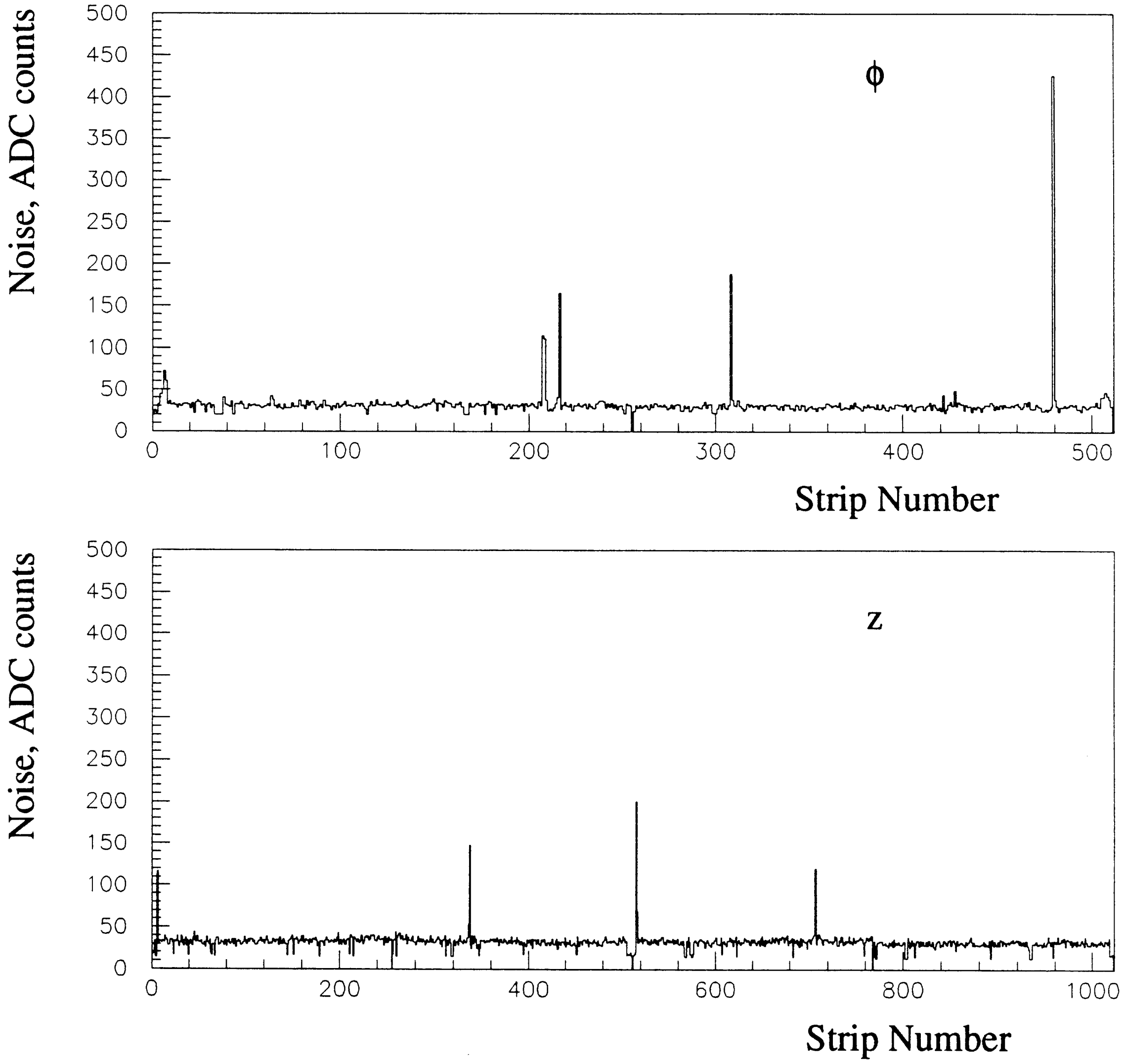


Figure 2

Figure 3




Noise, ADC counts
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Strip Number
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Figure 4

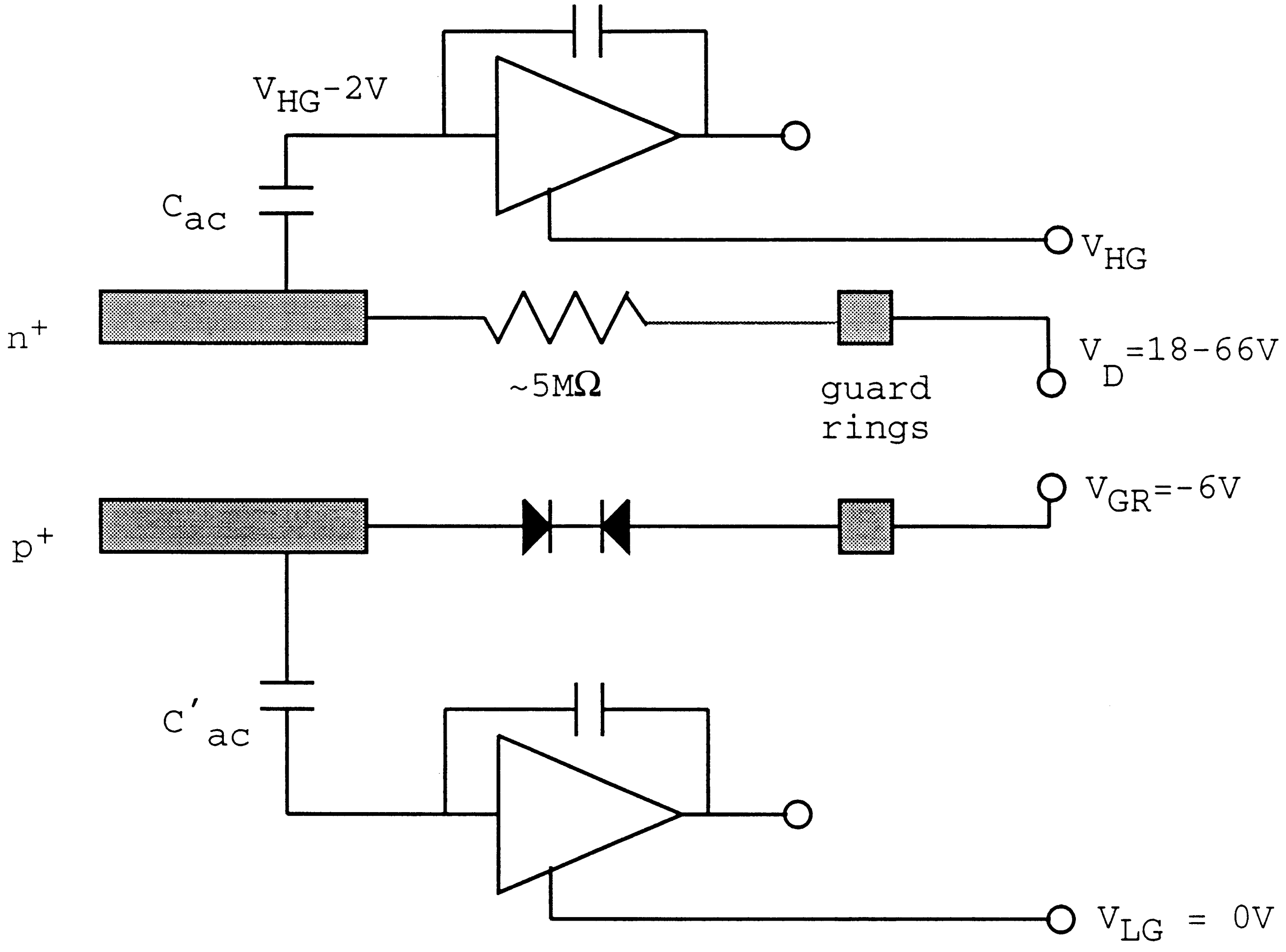

Figure 5