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DESIGN AND PERFORMANCE OF A NEW 307 MPIXEL CCD VERTEX DETECTOR*

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During the past year, the SLD Collaboration completed construction and began operation of a new vertex detector (VXD3) with 307,000,000 CCD pixels. This upgrade will improve the SLD measurement of the polarization-enhanced forward-backward asymmetry for b- and c- quarks and the precision of the measurement of the b-fraction in hadronic Z decays and opens the possibility to observe B_s^0-mixing. Full separation of primary, secondary and tertiary vertices is accessible.

1 Introduction

During 1996, the SLD Collaboration completed and installed a new vertex detector (VXD3) based on 96 CCDs of 13 cm^2 area each, for a total of 307,000,000 pixels. [1] It replaced the pioneering 120 Mpixel CCD vertex detector, VXD2. [2] Placed close to the e^+e^- intersection point, in conjunction with small SLC beam spots, VXD2 has provided SLD with excellent flavor-tagging for three years. The upgrade to VXD3 significantly improved performance and opened new, exciting possibilities for physics at SLD. Advances in the technology of CCD detectors made it possible to design a vertex detector with much better impact parameter resolution, larger solid angle coverage and virtually error-free track linking, all features which enhance SLD heavy quark measurements.

2 VXD3 Detector Design

The development of large area CCDs simplifies ladder design for VXD3, with only 2 CCDs covering the entire length of the 158 mm ladder, permitting a three layer system with practical mechanics. VXD3 provides complete azimuthal coverage out to $|cos\theta| = 0.85$ and provides two layer coverage to 0.90 (see Figure 1). Spatial resolution degrades little at small polar angles due to the thin 20 μm active EPI silicon layer.

With a beampipe inner radius of 23.5 mm, the layer-l radius is 28.0 mm; the layer-3 radius of 48.3 mm achieves the desired $|cos\theta|_{max} = 0.85$. With

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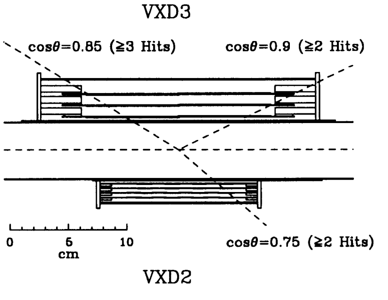

Figure 1: Comparison of the geometry of the new vertex detector (VXD3) with the old (VXD2), illustrated the expanded angular coverage and increased lever arm.

beryllium motherboard stiffeners, and CCDs thinned to $150\mu m$, a VXD3 ladder is < 0.4% radiation lengths thick. The 0.75 mm Be beampipe, 0.5 mm Be gas jacket, and $50\mu m$ Ti beampipe liner generate little multiple scattering. Lengthened lever-arms and reduced detector material will improve impact parameter resolution by about a factor of 2 compared to VXD2. VXD3 is nearly a standalone detector for impact parameter resolution. The expected VXD3 impact parameter resolution is

$$\sigma_{XY}(\mu m) = 9 \oplus \frac{29}{psin^{\frac{3}{2}}\theta} \qquad \sigma_{RZ}(\mu m) = 14 \oplus \frac{29}{psin^{\frac{3}{2}}\theta}$$

2.1 Mechanical Structure

The vertex detector is supported by instrument grade beryllium. The beryllium components are match pinned and doweled to stabilize the structure. Mating surfaces are lapped with one μm precision. The CCD ladders are supported at each end via beryllium rings mounted to the inner faces of the endplates. All joints between dissimilar materials allow for thermal contraction variation during cool-down. The vertex detector is operated at cryogenic temperature (–50° *C)* completely suppressing dark current and losses in charge transfer from radiation damage. Cooling is achieved with liquid nitrogen boiloff gas piped through fine holes in a beryllium jacket surrounding the beryllium beampipe. The vertex detector was surveyed with an OMIS II coordinate measuring machine to a few micron precision.

2.2 CCDs, Electronics, and Readout

The CCDs are n-buried channel devices fabricated on p-type epitaxial layer and having a p+ substrate. They have an active area of 80 mm $\times$ 16 mm. They are operated in a full-frame readout mode. The epitaxial layer is 18-22 μm thick, and the transverse pixel sizes are $(20\mu m)^2$. The readout register operates on two-phase clocking and the imaging area on three-phase. There are 4 readout nodes, one on each corner of the device, with 800,000 pixels per node, and a pixel readout rate of 5 MHz. Processing circuitry resides inside the SLD detector. The readout electronics consist of 16 analog-to-digital (A/D) boards close to the CCDs, connected with high speed optical links to FASTBUS Vertex Data Acquisition modules outside. The A/D boards have all CCD clocks and biases circuitry servicing 24 channels (6 CCDs) with amplifiers of gain 100, and 8-bit flash ADCs. Digitized signals are organized into serial data, and are transmitted via 1.2 GHz optical data link, using the Hewlett-Packard Gigabit Rate Transmit-Receive chip set, and FINISAR optical transmitters. The 307 Mbytes of raw data is reduced to a manageable size (100 kbytes) by hardware reconstruction of 2-d clusters with a threshold requirement that gives > 99% efficiency for minimum ionizing particles.

3 Performance

VXD3 data running began in April, 1996, and 50,000 Zs were collected by July, 1996. In normal beam conditions, the average data size is about 40kB, corresponding to a few thousand clusters, mostly from background tracks and X-rays with a density of a few per cm^2, or an occupancy of about 10^{-4}. Preliminary performance with initial alignment is presented (see Figure 2).

CDC tracks above 1 GeV/c are linked with at least two VXD3 layers with 99% efficiency and with three layers with 93%. The single hit resolutions are 17.2 μm in $r\phi$ and 14.4 μm in z (see Figure 3). The intrinsic resolutions obtained from tracks restricted to specific CCDs in each layer are 4.9 μm in $r\phi$ and 5.8 μm in z (see Figure 4).

The differences between these two sets result mainly from alignment errors and full resolution should approach the intrinsic resolution after a detailed track based alignment, as for VXD2. Heavy quark events have been reconstructed with both vertices clearly seen a few mm off the initial vertex in both views. Three dimensional vertexing capability is already very effective in purely tagging b-quark events with high efficiency, as it was with VXD2.

Several notable problems were encountered during commissioning. One channel (0.25% of the total area) does not respond. Charge leaks into neigh-

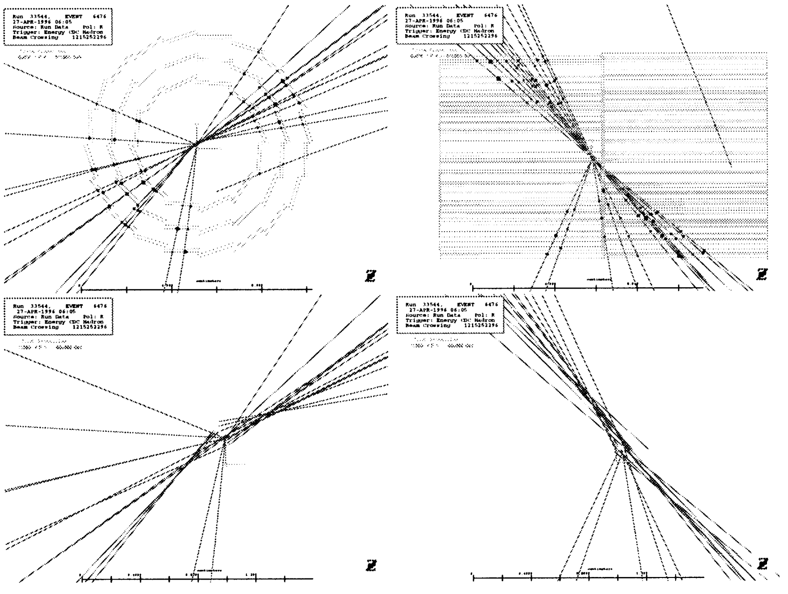

Figure 2: Candidate $e^+e^- \rightarrow Z^0 \rightarrow b\bar{b}$ event with lower image expanded ~ 6.5 times.

boring pixels in the read out register for two channels (0.5% of the total area), reducing efficiency (to ~ 50%) for these two CCDs; we expect to fix this in the next run by raising the R-clock voltage. Poor thermal contact between many A/D boards and their heat sinks results in overheated boards; this will be corrected. Spurious loss of communication between the A/D boards and the DA boards was cured by inactivating the electronics during beam crossing.

Acknowledgments

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References

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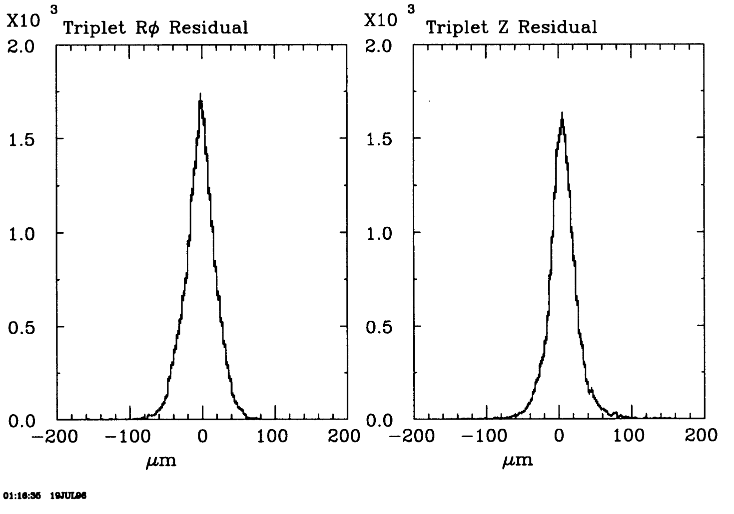

Figure 3: Residual distributions in $r\phi$ and z at layer 2 for tracks extrapolated between layers 1 and 3, demonstrating single hit resolutions of $\sigma_{r\phi} = 17.2\mu m$ and $\sigma_z = 14.4\mu m$.

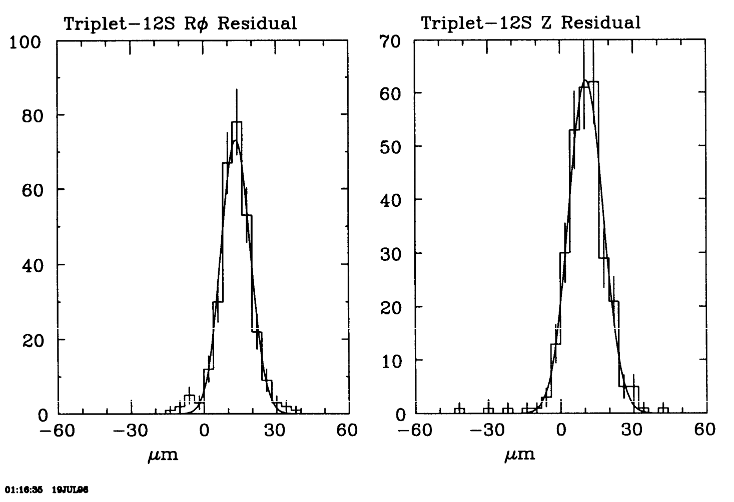

Figure 4: Residual distributions at layer 2 for tracks extrapolated between layers 1 and 3 for one triplet of CCDs, demonstrating single hit resolutions of $\sigma_{r\phi} = 4.9\mu m$ and $\sigma_z = 5.8\mu m$.

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