This Detector Can't be Built
(without lots of work)

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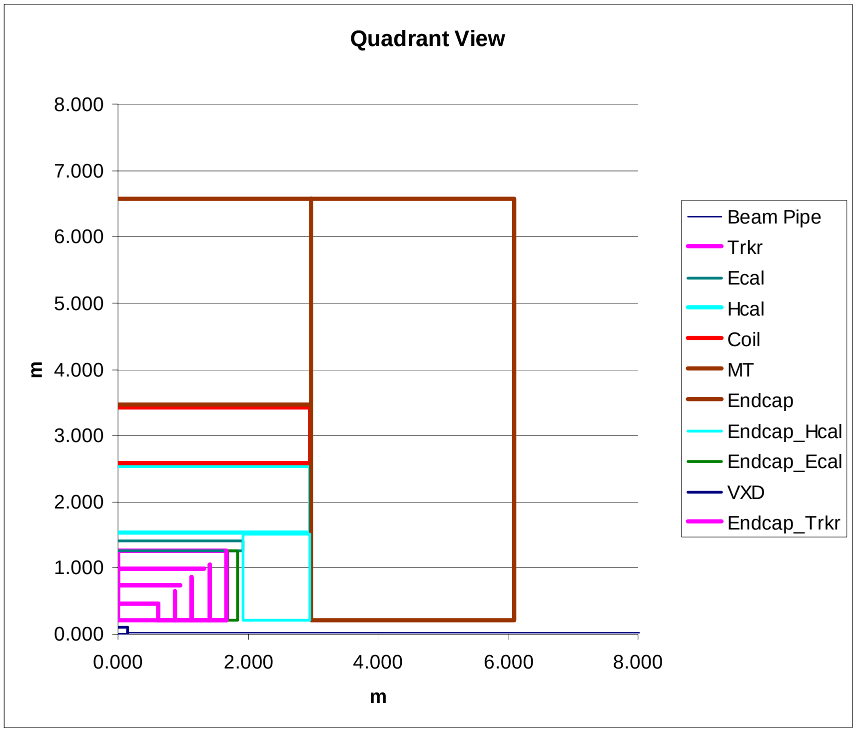
Most of us believe that e^+e^- detectors are technically trivial compared to those for hadron colliders and that detectors for linear colliders are extraordinarily trivial. The cross sections are tiny; there are approximately no radiation issues (compared to real machines!) and for linear colliders, the situation is even simpler. The crossing rate is miniscule, so that hardware triggers are not needed, the DAQ is very simple, and the data processing requirements are quite modest. The challenges arise from the emphasis on precision measurements within reasonable cost constraints.

The Silicon Detector, SD, is a "preconceptual" design of a high performance detector for the NLC, with reasonably uncompromised performance in general and stressing superb energy flow performance with its electromagnetic calorimeter (ECal). However, it is assumed from the beginning that funding will be very tight and that the detector costs must be constrained and rational. It also remains to be demonstrated by detailed simulation that many aspects of this performance are required by the physics.

A quadrant view of SD is shown in Figure 1. Working radially out, the detector begins with a 5 layer CCD vertex detector (VXD) with an inner radius of 1 cm. Tracking is provided by an array of 5 layers of silicon strip detectors arranged in barrels and planar endcaps. The tracker extends to 1.25 m, and is followed by an ECal consisting of alternating layers of tungsten and silicon diode detectors, totaling about 21 X_0 in about 30 layers. The silicon diodes are segmented into pixels about 1 cm across, and are read out independently, producing a "tracking" calorimeter. The ECal is followed by the hadronic calorimeter (HCal), consisting of alternating layers of radiator (probably copper or stainless) and inexpensive track counting detectors, perhaps a suitably reliable version of resistive plate chambers (R^2PC's). Outside the HCal is a 5 T solenoid. The perhaps unusually large field is chosen to sweep e^+e^- pairs away from the VXD, to achieve excellent tracking performance in the somewhat modest 1.25 m tracking radius, and to separate charged and neutral particles in jets for energy flow performance in the ECal. Outside the solenoid is a series of iron laminations interleaved with R^2PC's that track muons, with the iron serving additionally as the flux return.



The vertexing and tracking should be done with minimal multiple scattering so that the superb resolution of the CCD's or silicon strips is not degraded. Both tracking resolution and energy flow performance improve with the tracker radius squared, but the detector cost increases by approximately $2M per cm. As noted, the ECal is optimized for energy flow, but at this time, the case for energy flow has not yet been proven, and it is rather expensive. The high B field indeed cleans up the pair background better than the lower fields assumed by the other detector strategies and improves the tracking resolution, but it is higher than any existing detector solenoid.

The problem is that perhaps $300M (US accounting) would be available for an NLC detector, and the detector outlined above could not be built for that money with today's technology. All of the various subsystem technologies exist in some form, and no new detector principles are required, but extensive development is needed for every one. New ideas leading to better or cheaper detectors would be most welcome. Obviously, this is an argument for starting a significant level of support for detector R&D. It is clear that the detector performance goals can be compromised to lower the costs, but this is the wrong time. Compromises should await the results of a serious attack on the problems over the next 3 to 4 years. Below is a biased introduction to the R&D issues.

- VXD

The current generation of CCD's appear to be nearly satisfactory in terms of radiation hardness, pixel size, and readout speed. However, multiple scattering could be reduced if the CCD's were thinned to about 50 μm, and the CCD's were supported by being stretched from their ends rather than by a substrate. At the ends, the extensive cabling from earlier generations should be replaced by ASIC's bonded to the CCD ends, which should also significantly improve readout performance. The scattering could be further reduced by a very thin Be beam pipe using fixed end conditions. The actual physics improvements need further study.

- Tracker

ATLAS has developed a rather beautiful chirped interferometer alignment system allowing micron scale measurements over distances of meters between a tiny optical head and a corner reflector. The heads, connected to multiplexing apparatus by a fiber, permit construction of a complex geodetic grid tieing together the elements of a tracker. Could such a system reduce the requirements on the space frame precision and stability – thereby reducing its mass and cost?

The "natural" architecture for silicon strips would be ladders of 10 cm square detectors, with the strips daisy-chained for half the length of the full detector, similar to the GLAST design. The ladder would be read by an ASIC bump-bonded to the last detector of the chain. The ASIC would include all preamplification, digitization, data compression, and control necessary to drive a fiber, and it would include power pulsing to take advantage of the NLC's extraordinarily low duty cycle. It would be interesting to see if this relatively high capacitance structure could produce any timing information to help associate tracks with a bunch. Some part of the overall detector should deliver timing information to help suppress background processes.

- Calorimeter

The figure of merit for a Si-W energy flow calorimeter should be something like BR^2/σ_{eff}, where $\sigma_{eff}^2=R_m^2+\sigma_{pixel}^2$. Here B is the magnetic field, R the calorimeter radius, R_m the effective Moliere radius of the calorimeter, σ_{pixel} is a characteristic length of the pixels on the silicon. The wonderful 9 mm Moliere radius of tungsten is diluted by $(1+R_{gap}/R_w)$, where R_{gap} is the clearance between tungsten plates for the detector assemblies, and R_w is the actual tungsten thickness. R_w should be substantially less than 1 X_0 = 3.5 mm, say 2.5 mm. Then it is clear that R_{gap} should not exceed 2.5 mm, and 1.5 mm would be a very attractive goal. This will require some very clever electronic and mechanical integration.

The architecture might be hexagonal pixels with a "diameter" in the range of 5 to 10 mm, built on the largest readily available wafer in large hexagons. These would be 6 inch wafers today, and might be 300 mm in the future. Again, an ASIC is foreseen that would bump (or diffusion) bond to each wafer, so that only a few connections would be needed to the supporting motherboard. It would, of course, be more elegant if this ASIC could be part of the diode array proper, but this is probably a stretch for the high resistivity silicon. Again, all the data processing would be handled on this ASIC, but the output could be to a strip line feeding a data concentrator on the board. The shaping time should be optimized for good signal to noise so muons can be tracked, but with the very small diode capacitance, it might be possible to extract some timing information. These electronics developments are probably critical to taking advantage of the potential of Si-W calorimetry, and largely drive the architecture of the entire detector. Substantial progress should be demonstrated quickly!

We are used to thinking about channels of electronics, but that will not do for a detector of this scale with roughly 50×10^6 calorimeter pixels and 5×10^6 tracking strips. (We have gotten over channel counting for CCD pixels – SLD had over 3×10^8 pixels, but only 24 optical fibers taking data away from the detector.) The argument against channels, meaning separate signal pairs, etc., is made rather clear by multiplying those channel counts by costs per channel that probably lie in the $10 to $100 range. The readout must be organized into clusters of channels, where a cluster chip services as many pixels as can be rationally connected electrically.

The HCal is probably a sampling device, perhaps with a "digital" readout akin to a (reliable) RPC. Much work is required to demonstrate the technical performance of an RPC, in addition to the efforts that will be required to make them reliable. Perhaps more important from an R&D viewpoint is that the HCal, while itself of modest cost, can drive the scale of much of the rest of the detector. The most difficult decision is whether the HCal should be inside the coil, which crudely estimated would increase the cost by $36M for a 4 λ HCal.

- Magnet

The suggested solenoid field is 5 T, which is a factor of about 3 more than existing detector coils, and should be compared to CMS at 4 T. The stored energy is about 1.7 GJ, which is considerably larger than the largest operating example Aleph, at 130 MJ.

- Conclusions

The previous several years of NLC detector R&D has focused on simulation, particularly in the area of tool development. To make progress on a detector design, it is critical to verify what performance is really needed for the physics and demonstrate that the critical technology required to produce the desired performance can be implemented at finite cost. It is also important to support the universities so they are full participants.

Recent years have significantly eroded the engineering and support capabilities at the universities. One of the enduring benefits of the SSC was the work done with the support of the Texas National Research Laboratory Commission (TNRLC). The TNRLC supported the incremental costs associated with R&D for the SSC detectors, as well as some phenomenology and theory. A measure of its effectiveness is the rather large contributions of the US groups to LHC, which are based on work with a scale and impact much larger than the current DOE program. We urge the re-invention of an organization like the TNRLC for LC detector R&D.