SLAC–PUB–6264
July 1993
(E)

SUMMARY OF EXPERIMENTATION ISSUES*

WILLIAM W. ASH
Stanford Linear Accelerator Center,
Stanford University, Stanford, CA 94309 USA

1. Introduction

The conveners of the parallel session on Experimentation—Guy Coignet (LAPP, Annecy), Tom Markiewicz (SLAC), and Ron Settles (MPI Munich)—assembled a group that well represented the spectrum of topics and the international community that is doing the work. This paper is an attempt to summarize the thirteen talks given in that session, listed for reference in Table 1.

Since the speakers often covered similar topics from different viewpoints or reflected work going on in different labs, I have borrowed from each of the contributor's presentations and rearranged them according to the list of topics given in Table 2. I urge the reader to study each of the papers individually to get the full picture and avoid any unintentional oversights.

2. Machine Interactions

2.1 Beam Structure

Many machine concepts have been proposed for the next generation linear collider. A good representation of the parameters for these designs is included in an extensive paper on background issues by Chen et al.,[1] which was presented and extensively discussed at this conference. Rather than try to make long lists of comparisons and keep track of the changes in the machine designs, I will concentrate here on the 'JLC' and 'Tesla' designs as represented in this reference. I believe that these distinct approaches will illuminate the issues reasonably well.

The characteristics of interest from the experimenters' point of view are the bunch shape (which affects backgrounds) and the time structure (which affects detector response).

The bunch shape for the two approaches is shown in Fig. 1. Note the very small flat cross section of the JLC beam and the much larger and less flat Tesla profile. (For scale, the profile of the SLC beam as it is now operating is shown as well. Clearly, we are preparing for a very large step down in size.) The second part of the figure shows the length of the beams. The luminosity per bunch, given in the third part of the figure, is about the same for each approach, with the larger number of particles in the Tesla bunch compensating for its larger cross section.

The time structure for the two approaches is given in Fig. 2. The total number of bunches is about the same for each approach, but the Tesla bunches

---

* Work supported by Department of Energy contract DE–AC03–76SF00515.

Invited talk presented at the 2nd International Workshops on Physics and Experiments with Linear e^+e^- Colliders, Waikoloa, HI, April 26–30, 1993

Table 1. Talks presented in the parallel session on experimentation. They are arranged in order of presentation and not according to topics.

Background conditions for flat beam running at SLC	H. Band U. Wisconsin
Measurement of mini-jets at Tristan	T. Tauchi KEK
Fractional luminosity near the maximum energy in the presence of beamstrahlung	D. Schroeder Grinnell College
Support tubes for JLC vertex chambers and final quadrupole magnets — design studies	S. Kanda KEK
Interaction region studies for the NLC as pursued at SLAC	T. Markiewicz SLAC
Recent developments in CCDs suitable for linear collider vertex detectors	C. Damerell RAL
Studies of vertex detector design options using simulated b events	C. Bowdery U. Lancaster
Physics benchmarks for detector choice and machine performance discussed with alternatives	R. Settles MPI-Munich
Experimental challenges and opportunities at linear colliders	Y. Fujii KEK
Studies on detector options in the CLIC group including IP simulation and detector options	P. Grosse-Wiesmann CERN
Progress report on background simulation at the NLC	M. Ronan LBL
Z-pole option for Japan Linear Collider	T. Omori KEK
Gismo simulation program for detector optimization	A. Breakstone U. Hawaii

Table 2. Contents of this summary talk based on the talks presented in the Experimentation session. The talk titles and presenters are given in Table 1.

ORGANIZATION OF THE SUMMARY TALK	
1.	Introduction
2.	Machine Interactions
2.1	Beam Structure
2.2	Support Tube and Inner Detector
2.3	SLD Experience
2.4	Muon Background
2.5	Synchrotron Radiation Background
2.6	Beam-Beam Effects
2.7	Machine Interaction Summary
3.	Detector
3.1	Scenarios
3.2	Parameters and Overview
3.3	Vertexing
3.4	Acollinearity
3.5	Ten-degree hole
3.6	Two-photon Physics
3.7	Return to the Z
4.	Conclusions
5.	References

have a relatively wide 1-microsecond spacing, whereas the JLC bunches are 1.4 nanoseconds apart.

Roughly speaking, the much larger cross section of the Tesla beams makes vibration issues less severe, and its wider time spacing makes the separation of some backgrounds easier. On the other hand, the backgrounds generated per bunch are smaller in the JLC case due to the smaller number of electrons per bunch.

2.2 Support tube and inner detector

The idea of a common support tube to carry the final focus quadrupoles for both beams as well as the vertex detector has been presented at earlier meetings including LC92 at Garmisch-Partenkirchen and the Workshop on Final Focus and Interaction Regions at SLAC in May 1992. In this meeting, however, S. Kanda

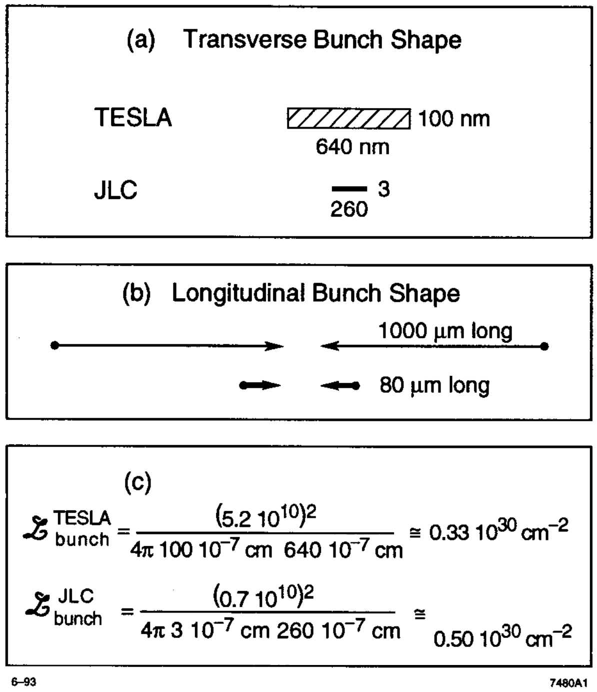

Figure 1. The bunch shapes for the Tesla and JLC generic machines. Section a) shows the very small flat cross section of the JLC beam and the much larger and less flat Tesla profile. (For scale, the profile of the SLC beam as it is now operating is about the size of the figure border. Clearly, we are preparing for a very large step down in size.) Section b) shows the length of the beams. The luminosity per bunch, given in the third part of the figure, is about the same for each approach, with the larger number of particles in the Tesla bunch compensating for its larger cross section.

presented simulations that demonstrate how important this concept is. Figure 3 shows the layout of the detector from the JLC design study. Note that the two pieces of the support tube come apart for the opening. In the closed configuration, the two sections are locked together to form a common structural element. But, suppose that connection were left flexible to simplify assembly. Kanda's modal analysis of the two cases shows that the vibration in the flexible case is many orders of magnitude worse than in the coupled case, clearly settling this design question.

T. Markiewicz presented data taken on a mockup of a support tube made at SLAC. The model was a 10-meter-long, 30-cm-diameter, 2.5-cm-thick aluminum tube with seismometers mounted on the tube 1.5 meters from the center to measure vibration at the critical location of the quadrupoles. The sum and difference signals distinguished between symmetric and antisymmetric motions. If the two sides of the final focus move symmetrically, the beams would continue to collide to first order. The antisymmetric motion, however, must be held to the same level as the spot size to maintain collisions. In their experiments, several sharp resonances

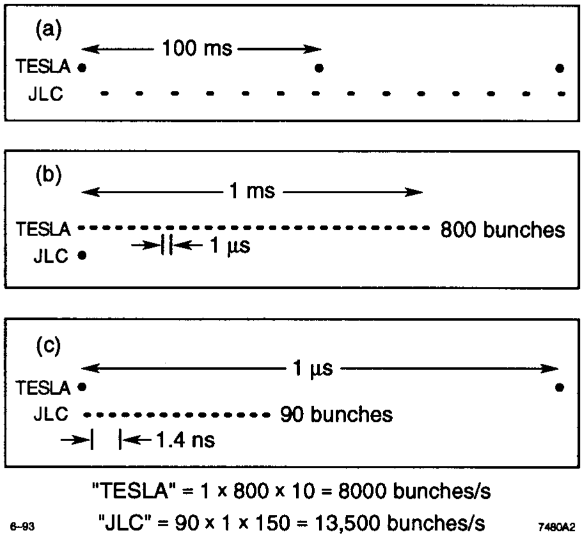

Figure 2. The time structure for the Tesla and JLC machines. The three different time scales illustrate the relatively wide 1-microsecond spacing for Tesla, whereas the JLC bunches are on 1.4 nanoseconds apart. The total number of bunches is about the same for each approach.

were found, as expected, with the dominant one, at around 40 Hz, giving an rms vertical motion of about 20 nm. This is acceptable to the Tesla configuration, but clearly intolerable for the JLC conditions with its few-nanometer vertical size.

Fortunately, another effort described by Markiewicz[2] promises a solution. Local stabilization of the magnetic field can be obtained by sensing the motion of the quadrupole with a coil mounted on a separate stand, isolated from the high frequencies. This signal can be amplified to drive correction coils in the quadrupole itself in classic feedback. A system using a permanent-magnet quadrupole is under construction and should be tested in the summer of 1993.

2.3 SLD Experience

The SLD experiment and its predecessor, the Mark II, have relevant experience in backgrounds at the SLAC Linear Collider. H. Band reported on the overall understanding of these processes, with particular reference to the recent results running with flat beams.

The primary backgrounds come from synchrotron radiation in the final focus quadrupoles and in muons generated upstream by collimators in the final optics element of the collider. The muon case was identified and solved by the Mark II group, which installed magnetized iron blocks at several points around the beamlines upstream of the detector. With experience in setting upstream collimators and a lower-emittance beam, this background source has deacreased to the point where only about 0.4 muons per pulse are seen in the SLD liquid argon calorimeter. This is easily recognized and removed from data.

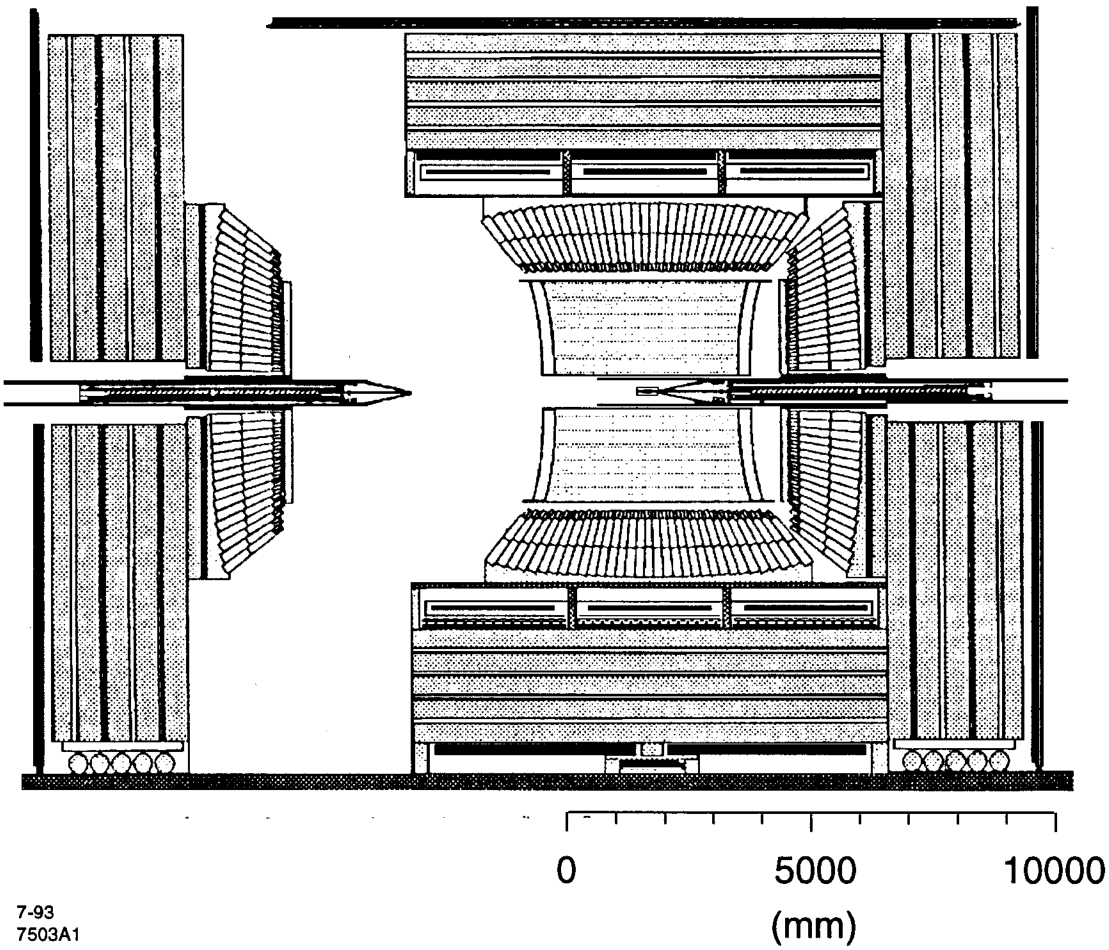

Figure 3. This schematic of a JLC detector design shows the two pieces of the support tube separated for the opening. In the closed configuration, the two sections are locked together to form a common structural element.

Synchrotron radiation is reduced by a series of masks that prevent all primary radiation from striking the detector components; only double- or triple-bounce photons enter the detector. The initial flux is strongly dependent on the tails of the primary beam, which are controlled by elaborate upstream collimation. Those photons that do get through to the drift chamber are measured as an occupancy, or fraction of available channels that are hit. At current operation, the occupancy of the central drift chamber of SLD is less than 5%, which is exceptionally clean.

Finally, there is an additional source of background in the form of rather stiff tracks in the central detector. Events produced by a tracking trigger show these particles originating from the beampipe walls and associated masks. These events, which amount to a few-tenths of a Hertz, are still under investigation.

SLC experiments indicate that backgrounds have in fact decreased as luminosity has increased in the past three years, and backgrounds are not a limitation to SLD physics analyses.

Band noted that future detector designs and data acquisition should be made robust and with a large safety margin to allow operation in less than ideal conditions. Beam control and stability are major issues, and further studies are essential to provide the more quantitative understanding of backgrounds required for experimentation at the next generation of machines.

2.4 Muon Backgrounds

Muon backgrounds have been considered in the basic design of next generation linear colliders, resulting in small bends and long straight sections after the final collimation sections. T. Markiewicz presented SLAC studies using magnetized iron shielding blocks in a 1-kilometer-long straight section. Monte Carlo studies for different configurations yielded solutions in which scraping of up to 1% of the beam in the upstream collimators produced no more than one muon in a detector—more than a factor on 100 improvement over the case of no shielding.

This calculation has not yet been made for the Tesla configuration, but it is probably about the same, assuming comparable collimation issues.

2.5 Synchrotron Radiation Background

A study of the synchrotron radiation based on a mask design developed by T. Tauchi and presented in the workshops referenced earlier was also presented by Markiewicz. The primary sources are the quadrupoles immediately upstream of the interaction point acting not on the core of the beam (whose radiation stays well inside the beampipe) but on the tails. The effect is critically dependent on that distribution and, hence, on the collimation schemes. Assuming a tail profile for the beam, synchrotron radiation was propagated to the masks with an EGS program used to trace the secondary radiation going into the detector elements.

The results were presented as backgrounds in a 14-mm-radius vertex detector and a 25-cm-radius central tracker for JLC-style parameters. With upstream collimation to about 8 sigma, it was expected that the vertex detector would register less than 1 hit per square millimeter per pulse train and fewer than 10 electron pairs per pulse train would show up in the drift chamber. These are considered acceptable.

This calculation has not yet been made for the Tesla configuration, but it may well be fewer, given gentler focusing.

2.6 Beam-beam Effects

Three different beam-beam interaction effects are relevant to experimentation at a next generation collider: electron-pair creation in the strong collision fields; hadron production by the high-energy photons produced by electron and positron bremsstrahlung in the collision fields; and distortion of the energy spectrum of the beams by those fields.

2.6.1 Pairs background

M. Ronan discussed pair production effects using the beam-beam simulation program originally developed by K. Yokoya. He merged the output of this code, called ABEL, with a GEANT* Monte Carlo to produce tracks for a detector on a JLC-style machine. In parallel, he presented preliminary results in which the tracks were carried through with an EGS simulation of the same detector elements used in the synchrotron radiation discussion. The vertex detector background is about 2 hits per square millimeter per bunch train and the drift chamber would see about 200 hits per train.

Assuming the same geometry, these results would scale to a Tesla-style machine by the ratio of the cross-section for producing the pairs. This is an intricate calculation that depends on the charge per bunch and the bunch shape. The parameters table in the paper by Chen et al.[1] includes a calculation of the number of beamsstrahlung photons produced per electron in bunches for these machines. The effective luminosity to produce pairs by photon-photon collisions is proportional to the square of the number of photons per electron times the normal bunch luminosity, $n_\gamma^2 L$. Thus, the Tesla-style machine would produce about 20 times larger background of this kind per *bunch* than the JLC-style. However, this is ameliorated by the much different time structure of the two machines. In the JLC case, we have added up the backgrounds from the 100 or so bunches in the train, since they are so closely spaced that this kind of background clutter would all be seen in any particular event. In the Tesla case, however, the individual bunches are spaced widely enough that background from one crossing would likely be electronically cleared before the next crossing. Comparing JLC backgrounds per *train* to Tesla backgrounds per *bunch* shows the Tesla case to be lower by about a factor of 5.

2.6.2 Photon-induced hadron backgrounds

The production of large-angle hadron backgrounds and minijets by the interbunch photon-photon collisions has been a very closely followed topic for the past several conferences. Early studies showed the potential for very serious backgrounds of a kind difficult to separate from actual events. This source is very sensitive to the beam-beam interaction parameters and, hence, has also engaged the interest of machine designers. There were several talks on the calculations at this workshop, as well as some lower-energy data on jets from this process given

---

* This is perhaps the place to introduce the new world in simulations. A. Breakstone discussed 'GISMO' in our session — an object-oriented program for detector simulations that will start to replace some of the techniques in current use.

by T. Tauchi in the experimentation session. This work has been well summarized here in the talks by S. Brodsky and D. Borden.

The direct estimate of this background is given by Chen et al.[1] as about 1.6 hadrons per bunch for Tesla and 0.07 hadrons per bunch for JLC. Note, however, that the JLC case is now quoted per *bunch* rather than *bunch train*. This significant reduction in the JLC case is made possible by assuming that the tracks and calorimeter hits in the detector have associated timing information down to the few-nanosecond level that would allow offline separation of the two-photon hadron background from primary events.

2.6.3 Spectrum effects

The strong interbunch interactions have the potential for introducing a significant energy spread affecting physics. This has been attacked in several models, including the one in Ref. 1. Another approach was presented by D. Schroeder, who gave plots of the fraction of luminosity with energy outside 1% of the mean as a function of the beamstrahlung parameter Υ_0 (which measures the mean magnetic field strength in the bunch) and the number of photons produced per electron in the collision. These curves allow one to study more easily the variation of the effect with changes in machine parameters.

The Tesla-style machine has a larger fraction of its luminosity outside the peak, but the actual effect needs to be evaluated more carefully, as it may also have a softer tail.

2.7 Machine Interaction Summary

A summary of the machine interaction effects is given in Table 3 for the two styles of machine. My thinking is that there are no show stoppers here for either style machine, but some work is still required. First, the active feedback required for the JLC needs to be demonstrated. Second, the background calculation tools need to be polished up and then applied directly to specific machine designs without relying on scaling.

3. Detector

3.1 Scenarios

R. Settles discussed the scenarios for developing detector(s) for a next generation linear collider. His work summarized particular studies using existing detectors applied to the topics of the higher energy, including SUSY, neutral Higgs, WW coupling, and charged Higgs. The conclusion was that for such a 'discovery run' based on 1–10 fb^{-1}, a LEP/SLC-style detector is perfectly acceptable. On the other hand, looking at precision measurements with 10–100 fb^{-1}/yr—such as the Higgs' branching ratios, Yukawa couplings, and disentangling the WW couplings—better detectors will be needed. This also pertains to a next step

Table 3. This table summarizes the problems of machine interaction for the two styles of machine design, JLC and Tesla. The differences are due to the much larger and longer beam shape in Tesla (which helps for vibration but aggravates some of the backgrounds) and tighter time structure in JLC (which aggravates some of the backgrounds).

MACHINE INTERACTION SUMMARY		
ISSUE	**JLC**	**TESLA**
vibration	active feedback required	no problem
muon background	1 muon/train	probably same
quad synchrotron radiation 14-mm VXD 25-cm CDC	 < 1 hit/sq mm train 10 e^{+-}/train	probably less
beam-beam pairs 14-mm VXD 25-cm CDC	 2/sq mm train 200 e^{+-}/train	with clearing between bunches will be smaller
two-photon induced hadrons	0.07 hadrons/bunch requiring timing & offline separation	1.6 hadrons/bunch
energy spread	needs evaluation for specific physics	probably worse

toward the 1-TeV regime. Settles suggested that we prepare for the precision measurements from the beginning.

3.2 Parameters and Overview

The parameters for the detector were addressed by Settles and by Y. Fujii. Table 4 gives the list presented by Fujii for the resolution and granularity in tracking and calorimetry.

The JLC group is moving toward a conceptual design to meet these criteria. The outline of such a detector, shown in Fig. 1, would incorporate their goals of hermiticity, good mass resolution, and b-tagging. This group has also begun an active R&D program on new components including a scintillation fiber test module for calorimetry. They aim for a complete design by the end of 1995.

Table 4. Parameters for a detector at a next generation collider from the talk by Y. Fujii.

DETECTOR	TYPE	CONFIGURATION	PERFORMANCE
VTX (Vertex Detector)	Silicon CCD	Pixel Size ; 25 μm Number of Layers ; 2 layers Layer Position ; r=2.5cm & 7.5cm Thickness ; 500 μm / layer $\lvert\cos\theta\rvert < 0.95$	Position Resolution ; $\sigma = 7.2$ μm Impact Parameter Resolution δ [μm]; $\delta^2 = 11.4^2 + (28.8/p)^2 / \sin^3\theta$
CDC (Central Drift Chamber)	Small-cell Jet Chamber	Radius ; r = 0.3 - 2.3 m Length ; l = 4.6 m Number of Sampling = 100 $\lvert\cos\theta\rvert < 0.70$ (full sampling) $\lvert\cos\theta\rvert < 0.95$ (20 samplings)	Position Resolution ; $\sigma_x = 100$ μm (/ axial wire) $\sigma_z = 2$ mm (/ stereo wire) Momentum Resolution ; $\sigma_{Pt} / Pt = 1.1\times10^{-4} Pt \oplus 0.1\%$ $\sigma_{Pt} / Pt = 5\times10^{-5} Pt \oplus 0.1\%$ (with vertex constraint)
CAL	Lead + Plastic Scintillator Sandwitch (Compensated)	EM part ; thickness = 29 Xo cell size = 10cm x 10cm HAD part ; thickness = 5.6 λo cell size = 20cm x 20cm Si Pad ; pad size = 1cm x 1cm $\lvert\cos\theta\rvert < 0.99$	Energy Resolution ; $\sigma_E / \sqrt{E} = 15\% / \sqrt{E} \oplus 1\%$ (e & γ) $\sigma_E / \sqrt{E} = 40\% / \sqrt{E} \oplus 2\%$ (hadron) Si Pad Position Resolution ; $\sigma = 3$ mm Si Pad e/π Rejection = 1/50
MUON	Single Cell Drift Chamber	Number of Superlayers ; 6 $\lvert\cos\theta\rvert < 0.99$	Position Resolution ; $\sigma = 500$ μm Pt > 3.5 GeV (barrel)
SOLENOID	Superconducting (Nb-Ti)	r = 4.5m , l = 10m Devided into 3 pieces	B = 2 T at I = 20 kA δB = ± 0.6 % at tracking region

* All momentum and energy are expressed in [GeV].

Another approach to a detector was presented by P. Grosse-Wiesmann, prepared with the CLIC group, in which a nearly spherical geometry for the inner region can be obtained as shown in Fig. 4. One of the more intriguing possibilities of this form is an array of silicon trackers at near perpendicular incidence. Another nice feature is the use of the outer shell as a structural member to join the two final focus elements.

3.3 Vertexing

The case for pixel-based vertex detection was made by C. Damerell, based on his experience with CCD devices in fixed-target experiments at CERN and in the SLD detector now running at the SLC. He quantified the background and radiation issues for these cases and extrapolated to a next generation collider.

For comparison, he assumed a microstrip-based detector with a similar geometry. Damerell notes that the much larger area of the strip intercepts much more background at the inner radius such that any channel will have a much larger

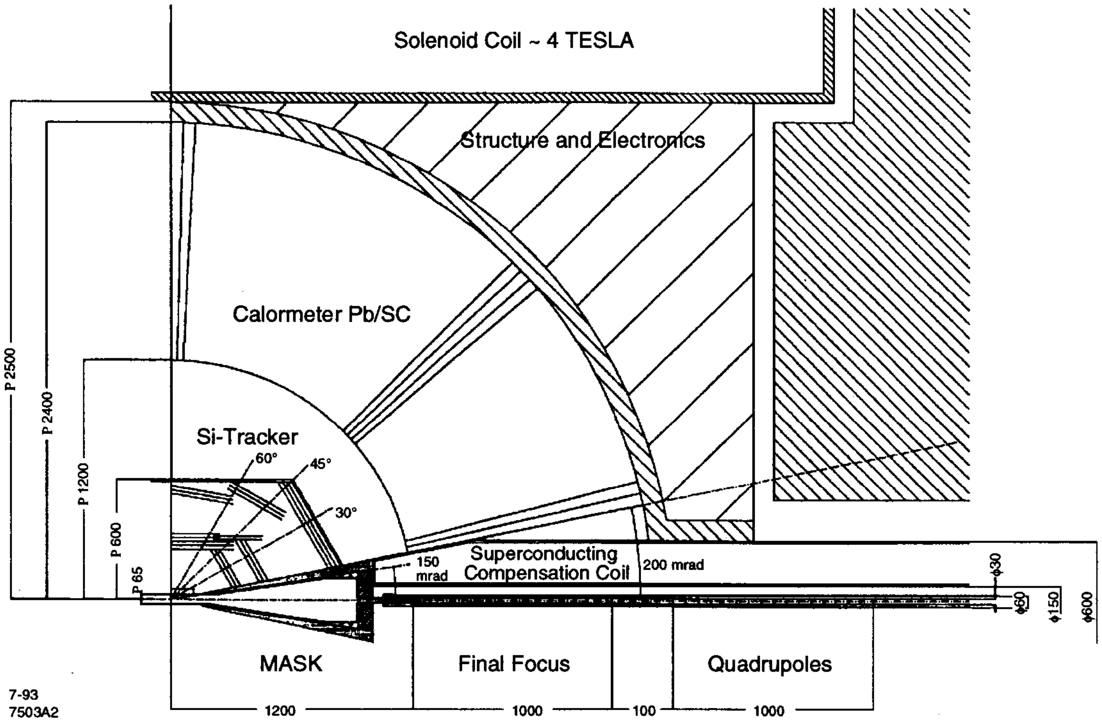

Figure 4. Outline of a detector from a CLIC study by P. Grosse-Wiesmann. Note the nearly spherical geometry, especially as exploited in the disposition of central silicon trackers, and the use of the outer shell as a structural member joining the two sides.

probability of a merging hit per track. This is shown graphically in Fig. 5. He concludes that pixel-based detectors will give greatly improved impact parameter precision at all momenta. A corollary of this study seems to be that at a larger radius, the background is sufficiently dispersed that the much-cheaper strip technology can make a practical central tracker.

In parallel, C. Bowdery simulated such a detector in the physics environment of the next collider, providing both criteria for resolution and processes for which the effect of background-induced tracking ambiguities could be evaluated. The driving result is that given a small-enough beampipe radius and expected pixel precision, efficient reconstruction of heavy flavor and τ lepton decay topologies should be possible in every event.

3.4 Acollinearity

The problem presented by the energy tail produced by beamstrahlung has been looked at by Frary and Miller[3] in earlier conferences and is discussed again here. The point is that one must monitor carefully the spectrum of the colliding beams

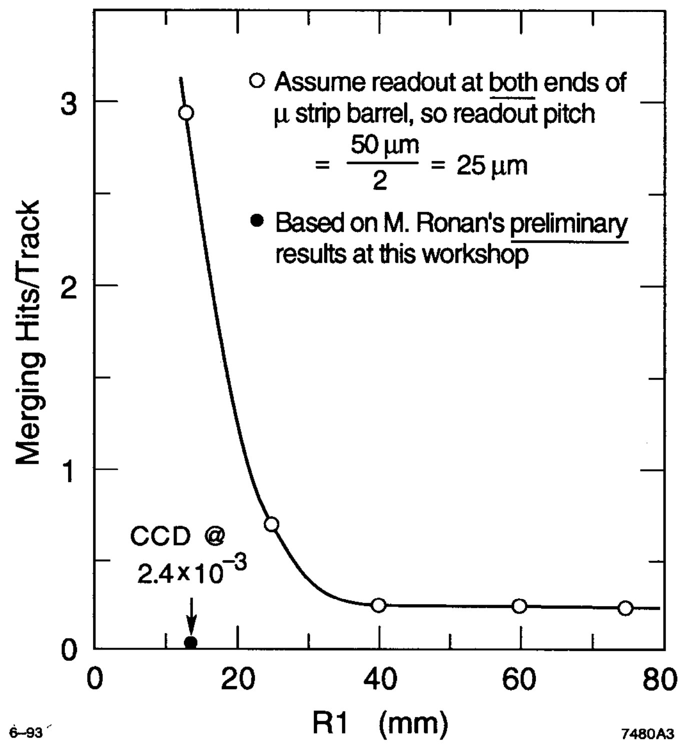

Figure 5. The number of merging tracks due to spurious hits from background increases dramatically as the radius of the detector decreases. The larger area of silicon strips drives the fraction to uncomfortably large values for the small radii required for good resolution on vertex reconstruction. Pixel-based CCDs have extremely low multiple hit probability at the smallest practical beampipe radius.

in order to have a chance of untangling energy-dependent physics, especially the top-antitop threshold. Their idea is to look at the acollinearity distribution ($\theta_A = (\Delta P/P) sin\theta$) in the intermediate range of Bhabha scattering angles $300 < \theta < 800$ mrad. This should be considered a basic design criterion in discussions of detector designs.

3.5 Ten-degree Hole

In most of the detector discussions, the region of polar angle less than ten degrees (175 mrad, $cos\theta > 0.985$) is given away to the masks and machine support with little further interest. True, there will be masks in the region, but space is certainly being made for the luminosity monitor and presumably other modifications could be made if physics demands.

In the Gamma-Gamma Physics parallel session of the conference, D. Miller looked at "Deep Inelastic Collisions with Beamstrahlung Photons." In particular, he notes that one could detect 4×10^4 $e\gamma$ events in the range $100 < Q^2 < 250$ $(GeV/c)^2$ with $x < 0.1$, provided one instrumented a hardened tagger inside the 40 mrad mask.

3.6 Two-photon Physics

There was no discussion in the Experimentation parallel session on two-photon physics. W. Vernon[4] indicated that most of the interest is now in laser-generated photon beams that would require completely new interaction region hardware. Perhaps one might want to consider the possibility of interchanging the inner tube section from an otherwise common detector. Meanwhile, traditional two-photon physics has not been pushed too much, but it may be appropriate to start thinking of mask modifications now.

3.7 Return to the Z

T. Omori brought to our session an idea being discussed now with the machine builders, in which very high luminosity running at the Z (or other critical energies) could be available.

He pointed out that this option cannot be simply obtained by turning down the gradient or back-phasing sections of the full machine, as the full loading of the sections is intimately related to the stability required. He proposed instead that a transport line be added to the machine to bring the beam down from the damping ring region to the last 50-GeV section of the linac and inject there, leaving the first 250 GeV section bypassed.

With this, luminosities at the Z^0 of $10^{33} cm^{-2} sec^{-1}$ would be available, not only for the physics at these high luminosities, but also for calibrating tracking and calorimetry in the detector.

4. Conclusions

Design and understanding of how to approach experimentation at the next linear collider have advanced dramatically in the few years of the studies by the physics and machine groups. The topics of this workshop point, I believe, to a program for the next year or so as follows:

1. Backgrounds
   (a) complete calculations for all machine designs
   (b) optimize masking
   (c) interact with machine designers
   (d) iterate
2. Support Structure
   (a) build prototype support tube with masks and magnets with thin central section and expected services of water and power
   (b) test feedback
   (c) interact with machine designers
   (d) iterate
3. Optimize Vertex Detector
   (a) study minimum radius versus background and resolution
   (b) develop electronics, cabling and cooling requirements
   (c) interact with machine designers
   (d) iterate
4. Tracking and Calorimetry — pursue new ideas and geometries.
5. Run the SLC/D
   (a) new third-order final focus optics
   (b) lower impedance of damping ring
   (c) modify ring lattice
   (d) increase polarization and current of gun
   (e) second generation feedback
   (f) optical wire scanners
   (g) quantitative background studies

5. References

1. P. Chen, T.L. Barklow, and M.E. Peskin, "Hadron Production in $\gamma\gamma$ Collisions as a Background for e^+e^- Linear Colliders," SLAC–PUB–5873, presented at *LCWS Conference*, Waikaloa, HI, May 1993.
2. G. Bowden, SLAC NLC Group, private communication.
3. M.N. Frary and D.J. Miller, "Monitoring the Luminosity Spectrum," DESY 92-123A, Nov. 1991.
4. W. Vernon, private communication, *LCWS Conference*, Waikaloa, HI, May 1993.