The Silicon Detector (SiD)
and Linear Collider Detector R&D in Asia and North America*

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Abstract

In Asia and North America research and development on a linear collider detector has followed complementary paths to that in Europe. Among the developments in the US has been the conception of a detector built around silicon tracking, which relies heavily on a pixel (CCD) vertex detector, and employs a silicon tungsten calorimeter. Since this detector is quite different from the TESLA detector, we describe it here, along with some of the sub-system specific R&D in these regions.

INTRODUCTION

The TESLA detector, which has been developed by the ECFA-DESY Studies over the past several years, optimizes the design of the detector around a specific set of assumptions. Alternative assumptions exist, and to a varying degree, have been applied to the design of other possible linear collider detectors, such as the JLC [1] Detector, the North American Large Detector, and the North American Silicon Detector (so-called SiD). Table 1 summarizes the properties of these differing choices. This table shows a number of similarities between the detectors:

- both TESLA and the Large Detector use TPC trackers.
- both TESLA and the Silicon Detector use silicon/tungsten for the EM calorimeter.
- The Large Detector and the JLC Detector choose scintillator tile with lead for EM and hadron calorimetry.

Other details vary, including the choice of magnetic field, which ranges from 3 up to 5 Tesla.

Each of these designs is guided by the physics goals, which lead to the following principal detector goals:

- Two-jet mass resolution, comparable to the natural widths of the W and Z for an unambiguous identificaion of the final states.
- Excellent flavor-tagging efficiency and purity.
- Momentum resolution capable of reconstructing the recoil-mass to di-muons in Higgs-strahlung with resolution better than the beam-energy spread.
- Hermeticity (both crack-less and coverage to very forward angles) to precisely determine the missing momentum.
- Timing resolution capable of separating bunch-crossing to suppress overlapping of events.

THE SILICON DETECTOR

The "Silicon Detector" (SiD, illustrated in Figure 1) was conceived as a high performance detector for the NLC, achieving all of the physics goals enumerated above, with reasonably uncompromised performance, but constrained to a rational cost. The strategy of the "Silicon Detector" is based on the assumption that energy flow calorimetry will be important. While this has not yet been demonstrated in simulation by the US groups, the TESLA Collaboration has accepted this and it seems probable that the US community will eventually agree.

Figure 1: The Silicon Detector.

The strategy of energy-flow calorimetry leads directly to a reasonably large value of BR^2 to provide charged-neutral separation in a jet, and to an electromagnetic calorimeter (EMCal) design with a small Moliere radius and small pixel size. Additionally, it is desirable to read out each layer of the EMCal to provide maximal information on shower development. This leads to the same nominal solution as TESLA: a series of layers of about 0.5 X_0 Tungsten sheets alternating with arrays of silicon diodes. Such

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* The authors acknowledge the help of the following people in preparing this overview: Gene Fisk, Ray Frey, John Jaros, Tom Markiewicz, Bruce Schumm, Eric Torrence, and Jae Yu.

[1] The name JLC was changed to GLC in April, 2003.

	TESLA	SiD	LD	JLC
Tracker type	TPC	Silicon	TPC	Jet-cell drift
ECal				
$R_{\min}$ barrel (m)	1.68	1.27	2.00	1.60
Type	Si pad/W	Si pad/W	scint tile/Pb	scint tile/Pb
Sampling	$30 \times 0.4X_0$ $+10 \times 1.2X_0$	$30 \times 0.71X_0$	$40 \times 0.71X_0$	$38 \times 0.71X_0$
Gaps,active(mm)	2.5 (0.5 Si)	2.5 (0.3 Si)	1 (scint)	2 (1 scint)
Long. readouts	40	30	10	3
Trans. seg. (cm)	≈ 1	0.5	5.2	4
Channels ($\times 10^3$)	32000	50000	135	144
$z_{\min}$ endcap (m)	2.8	1.7	3.0	1.9
HCal				
$R_{\min}$ (m) barrel	1.91	1.43	2.50	2.0
Type	T: sc. tile/steel D: digital/steel	digital/RPC Cu or steel	scint tile/Pb	scint tile/Pb
Sampling	$38 \times 0.12\lambda$ (B), $53 \times 0.12\lambda$ (EC)	$34 \times 0.12\lambda$	$120 \times 0.047\lambda$	$130 \times 0.047\lambda$
Gaps,active(mm)	T: 6.5 (5 scint) D: 6.5 (TBD)	1 (TBD)	2 (scint)	3 (2 scint)
Longitudinal readouts	T: 9(B), 12(EC) D: 38(B), 53(EC)	34	3	4
Transverse segment. (cm)	T: 5–25 D: 1	1	19	14
$\theta_{\min}$ endcap	5°	6°	6°	8°
Coil				
$R_{\min}$ (m)	3.0	2.5	3.7	3.7
B (T)	4	5	3	3
Comment	Shashlik ECal option in TDR discontinued		option: Si pad sh. max det	sc. strip (1cm) shower max det (2 layers)

Table 1: Comparison of Detector Configurations

a calorimeter is expensive, and its cost is moderated by keeping the scale of the inner detectors down. This has two implications: the space point resolution of the tracker should be excellent to meet momentum resolution requirements in a modest radius detector; and the design should admit high performance endcaps so that the barrel length (or cosθ_{Barrel}) will be small.

It is expected that track finding will largely be done in the 5 layer pixellated vertex detector, and the so-called tracker will primarily make the momentum measurement("Momenter"?), and improve the impact parameter measurement, and consequently refine the vertex reconstruction, as well as participate in the reconstruction of neutral strange particles. Strange particle decays in the tracker will be reconstructed from stubs in the EM calorimeter matched to hits in the silicon strips.

The last real strategic question is whether the Hadronic Calorimeter (HCAL) will be inside or outside the coil. Locating the HCAL inside the coil permits reasonably hermetic calorimetry, but it costs a larger, more expensive coil and more iron to return the flux. It is assumed that the detector will have a "standard" ultra high performance vertex detector based on CCD's (or an equivalent thin, small pixel technology), and that a muon tracker will be interleaved in the iron flux return utilizing reliable RPC's or equivalent.

These considerations lead to a first trial design with a tracking radius of 1.25 m and a field of 5 T. The field is set high to get a large BR^2, and also provides a safety margin of protection for the vertex detector against the massive number of electron-positron pairs at the interaction point. This choice makes BR^2 = 8, compared to 10 for TESLA and 12 for the North American Large Detector. The baseline tracker is 5 layers of silicon microstrips (silicon drift detectors are under consideration as an option) with a cosθ_{Barrel} of 0.8. A set of 5 silicon strip disks is arranged as to complete the acceptance. It is made of thinned silicon squares daisy chained together and read out on the ends, and supported by a low mass carbon fiber space frame. The HCAL is chosen inside the coil, and the radiator is Stainless Steel. The quadrant view is shown in Figure 2, and the major dimensions are tabulated in Table 2.

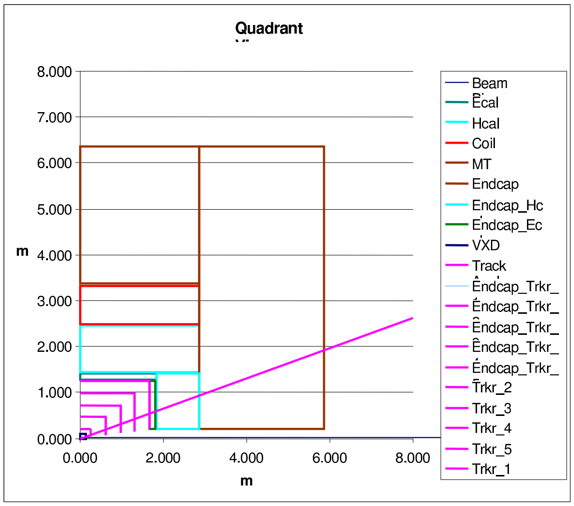

Figure 2: Quadrant View of the Silicon Detector.

Detector	Radius (m)		Axial(z)(m)	
	Min	Max	Min	Max
Vertex Detector	0.01	0.10	0.00	0.15
Central Tracking	0.20	1.25	0.00	1.67
Endcap Tracker	0.04	0.20	0.27	1.67
Barrel Ecal	1.27	1.42	0.00	1.84
Endcap Ecal	0.20	1.25	1.68	1.83
Barrel Hcal	1.44	2.46	0.00	2.86
Endcap Hcal	0.20	1.42	1.84	2.86
Coil	2.49	3.34	0.00	2.86
Barrel Iron	3.37	6.36	0.00	2.87
Endcap Iron	0.20	6.36	2.87	5.86

Table 2: SiD Major Dimensions

Tracker

The tracker resolution versus cosθ is shown in Figure 3. The resolution at 90^0 as a function of the tracker radius is shown in Figure 4 for the high momentum of p = 250 GeV/c, illustrating the choice of the 1.25 m outer radius. The high momentum resolution of the tracker is analyzed as a system with the 5-layer vertex detector. The low momentum track finding performance has not yet been calculated. Note that the tracker should be considered with the 5 layer vertex detector as a tracking system. It is assumed that the barrel readout is only at the ends of each layer, and that its mass has been minimized by ASIC's. Note that the required duty factor of a few hundred nanoseconds (a few microseconds in probable reality) every 8 milliseconds, is tiny compared to ATLAS, and that thermal management should be straightforward assuming power pulsing. The reasons for considering a silicon strip tracker are that its point resolution is excellent, leading to excellent high momentum resolution; that its barrel end structure should be thin compared to a TPC leading to better performance from disk endcaps; and that the silicon should be extremely robust in the questionable backgrounds of a linear collider. On the other hand, it will be challenging to read out the long strips with good noise performance and to keep the overall thickness of the structure very small.[2]

The vertex detector is assumed to be a CCD vertex detector, built of CCDs of optimal shape, with multiple readout nodes $(\tilde{2}0)$ for speed, thinned ($< 100\mu$m), with improved radiation hardness, and low power. A readout ASIC is mounted at the CCD, with output through fiber optics. This is a modest extrapolation from SLD's VXD3, with about 3 times the number of pixels.

EM Calorimeter

The EMCal consists of layers of tungsten with gaps sufficient for arrays of silicon diode detectors mounted on G10 mother boards and for a thermal conductor to provide heat removal. The diode arrays are hexagonal pixels, approximately 5 mm across. The thickness of these gaps is a major issue, in that it drives the Moliere radius of the calorimeter. A thickness of 2.5 mm seems plausible now, accommodating a 0.3-0.5 mm silicon wafer, a 0.5 mm G10 carrier, a 1 mm Cu thermal conduction sheet, and 0.5 mm of clearance. Conversely, 1.5 mm seems barely plausible but is an interesting goal! A stacked assembly rather than insertion into a slot is assumed. For now, we assume a 2.5 mm gap.[3]

The readout electronics from preamplification through digitization and zero suppression will be developed on a single chip that will be bump or diffusion bonded to the

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[2] Recent designs are considering individual readout of each detector to provide timing tags and lower occupancies.

[3] Recent work indicates that 1.5 mm or somewhat less should be possible.

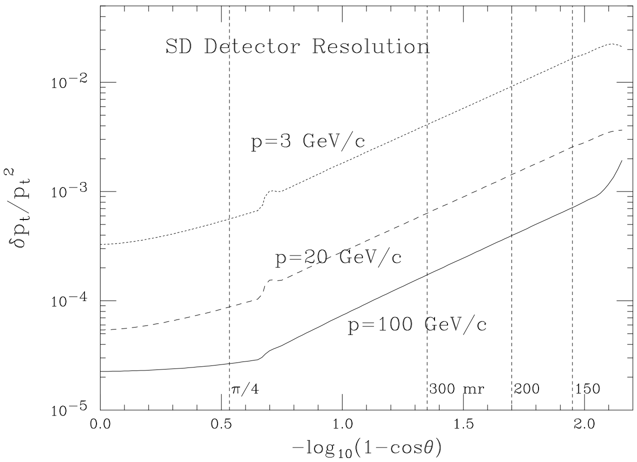

Figure 3: Momentum resolution $\Delta p_t/p_t^2$ as a function of cosθ, specifically $-log_{10}$(1-cosθ), for momenta of 3 GeV/c, 20 GeV/c, and 100 GeV/c. The values of the function for θ = π/4, 300 mr, 200 mr, and 150 mr are indicated by the vertical dashed lines.

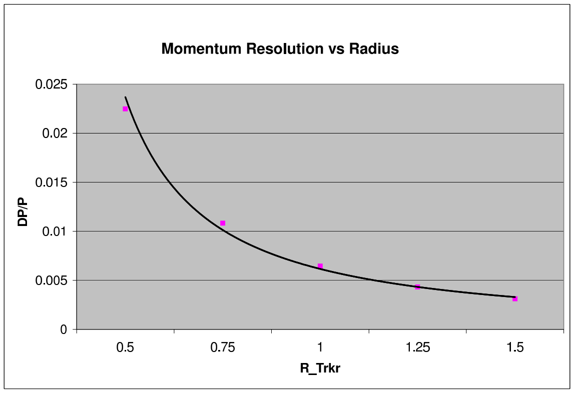

Figure 4: Momentum Resolution at p = 250 GeV/c vs. radius for the SiD tracker system.

wafer of detector diodes. Figure 5 illustrates the center of one 1000 pixel silicon wafer, with the bump bond array at the center, and the traces from the pixels to the bump bond array. Thus it is expected that the pixel size on the wafer will not affect the cost directly. Shaping times would be optimized for the (small) capacitance of the depleted diode. Recent work indicates that it may be possible to get timing information from each pixel, with localization to about a bunch within a train. Figure 6 is a cross-sectional view in the vicinity of the readout chip.

Thermal management is a fundamental problem for the EM Calorimeter as envisoned here with the deeply embedded electronics. With a power pulsing duty factor of 10^{-3} (which is possible for the X-Band collider), each wafer might generate 20 mW average power. Preliminary calculations indicate a water cooled heat sink at the outer edge of an octant, conducting heat through a 1 mm thick copper plane sandwiched with tungsten and G10, will develop a 14^0C temperature differential. This is acceptable. Whether the electronics can maintain adequately low noise in the presence of this power pulsing remains to be demonstrated.

W Thickness	2.5 mm
Gap	2.5 mm
Layers	30
Total X_0	21.4

Table 3: SiD Electromagnetic Calorimeter Parameters

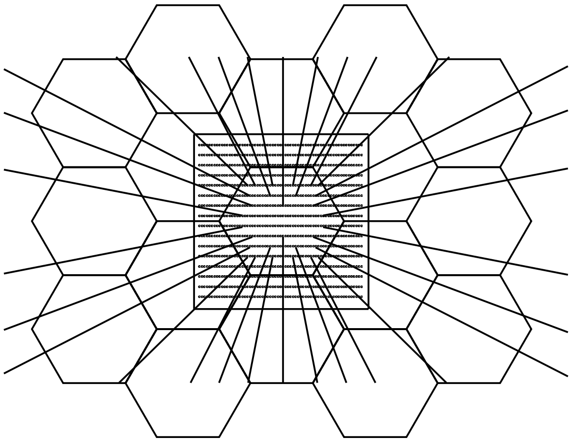

Figure 5: The center of one 1000 pixel silicon wafer showing the bump bond array at the center for the single readout chip. A few representative traces from pixels to bump bond array are shown.

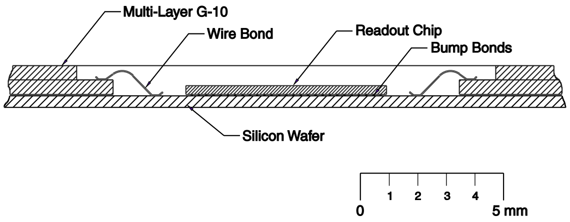

Figure 6: Cross-sectional view in the vicinity of the EM Calorimeter readout chip.

Hadron Calorimeter

The HCal is chosen to lie inside the coil. This choice permits much better hermeticity for the HCal, and extends the solenoid to the endcap flux return. This makes a more uniform field for the track finding, and simplifies the coil design. The HCal radiator is a non-magnetic metal, probably copper or stainless steel. Lead is possible, but is mechanically more difficult, particularly since the EMCal is supported by the inner layer of the HCal. The detectors could be “digital”, with high reliability RPC’s assumed. Studies are underway to determine the performance of the “digital” approach.

The HCal is assumed to be 4 λ thick, with 46 layers of radiator 5 cm thick alternating with 1.5 cm gaps.

Coil and Muon Tracker

The coil concept is based on the CMS design, with two layers superconductor and stabilizer. The stored energy is 1.4 GJ, compared to about 2.4 GJ for the TESLA detector and 1.7 GJ for the “L” detector. The coil ΔR is 85 cm.

The flux return and muon tracker is designed to return the flux from the solenoid, although the saturation field for the iron is assumed to be 1.8 T, which may be optimistic. The iron is laminated in 5cm slabs with 1.5 cm gaps for detectors.

Forward Detector

Figure 7 shows the SiD forward system. This figure illustrates the forward masking and magnets, and the tracking, calorimetry, and luminosity-pair monitor. Figure 8 shows the beampipe opennings in the luminosity-pair monitor located 3.5 meters from the IP.

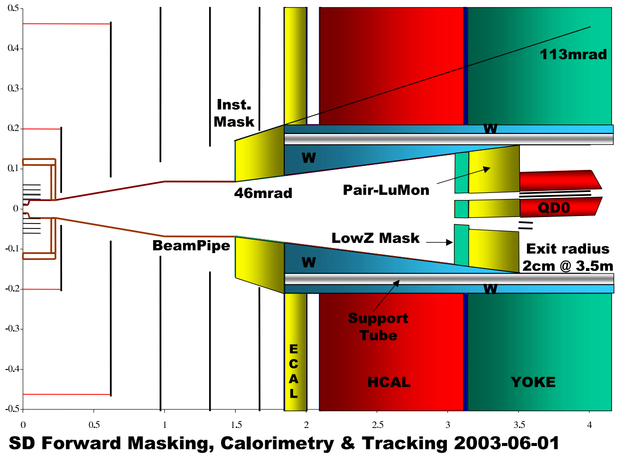

Figure 7: Schematic of the forward region of SiD, showing the forward masking and magnets, and the tracking, calorimetry, and luminosity-pair monitor.

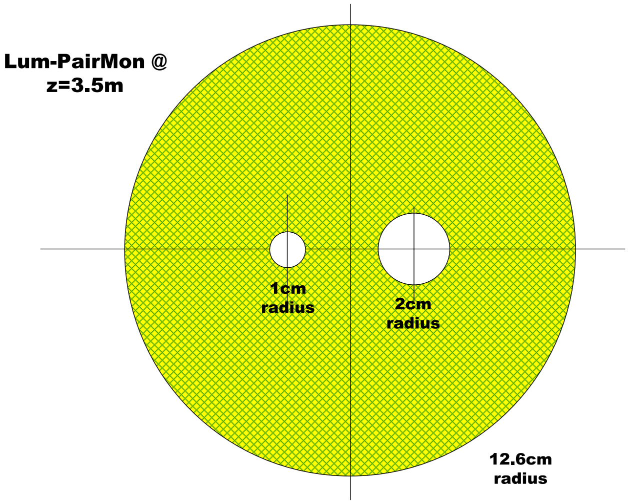

Figure 8: Cross section of the luminosity-pair monitor in the SiD forwrad system at z=3.5m.

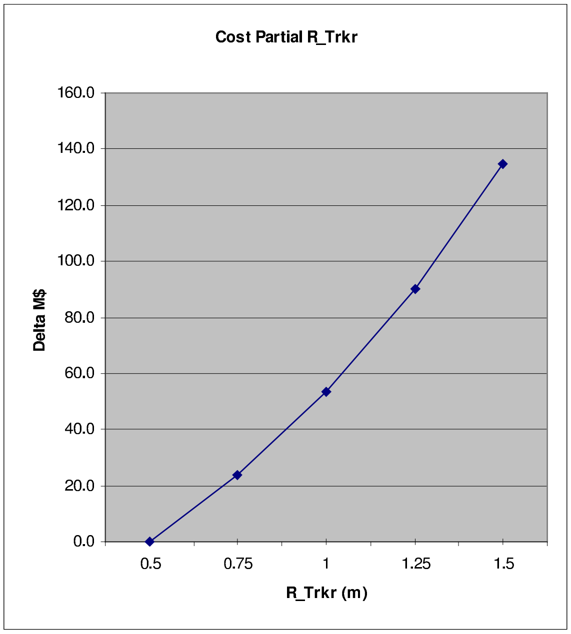

Figure 9: Cost differential versus tracker radius.

Costs

The “complete” cost estimate is in a separate document. A crude design code was written in Excel to keep the detector nominally consistent as parameters were varied which allows the estimation of some of the cost partial derivatives. The reader is cautioned that these are rather preliminary estimates.

The detector cost derivatives due to the major tracker parameters are shown in Figures 9 and 10.

The SiD tracker outer radius is nominally set to 1.25 m and cos θ_{Barrel}=0.8. A further interesting partial is the cost dependence on the thickness of the HCal. Although the HCal itself is not particularly expensive, it drives the coil and flux return size. The estimated values are shown in Figure 11.

The “more complete but extraordinarily preliminary” SiD total cost estimate is calculated mostly using numbers from the other North American detector costing exercises.[2] At this time the total materials and supplies (M&S) estimate is \$183M, the Labor estimate is \$55M, and contingency is \$84M, for a total of \$322M.

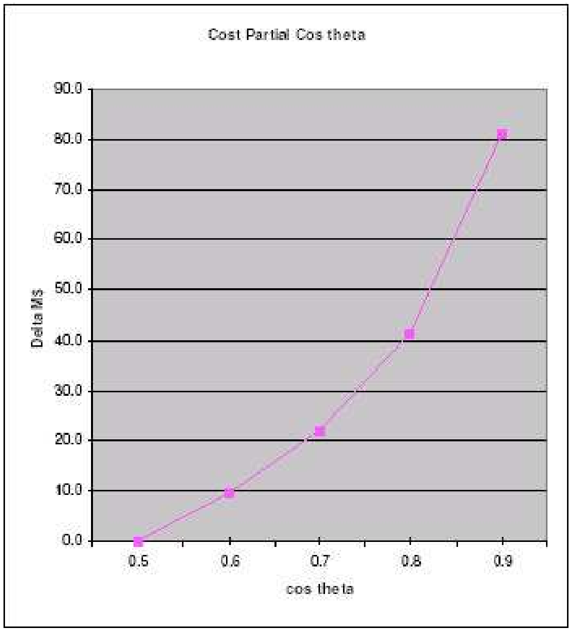

Figure 10: Cost differential versus tracker barrel angle.

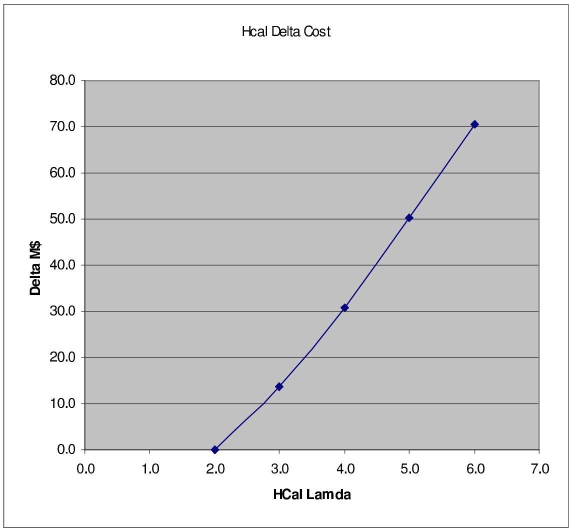

Figure 11: Cost differential versus hadron calorimeter thickness.

DETECTOR R&D IN NORTH AMERICA

The detector R&D in North American on linear collider detectors is diverse, and has not been aimed at any specific detector configuration. Following several years of support for simulation, the effort is now transitioning into an invigorated hardware effort. Funding for this new era is now established.

Below we list many of the tasks that are under investigation (this is not an inclusive list; there are other efforts).

Tracking

Tracking has focussed on three main R&D thrusts:

- Simulation
- Gaseous Tracking (TPC)
- Solid-state Tracking (μ-strips and silicon drift)

The simulation has been aimed at establishing tracking specifications, such as resolution and coverage, and in comparing and qualifying technologies.

Future goals for the simulation will include:

- Refine Tracker Requirements
  - SUSY (central at Michigan, forward at USCS)
- Explore Alternatives (not yet fully underway)
  - TPC vs. silicon drift
  - All-axial central μ-strip tracking
  - Forward tracking scenarios
  - With GEANT-based background included
- Tracking/Calorimeter Interface Issue
  - Track-cluster matching
  - Calorimeter-assisted VEE finding

Several Canadian and US groups are working on gaseous tracking. Their objectives are:

- Explore readout choice and design
- Gas selection (neutron backgrounds, diffusion)
- Compact electronics

Test chambers are being studied at Carleton, Victoria, and Cornell. GEM production is carried out at MIT (Microsystems Technology Laboratory) and proposed at Louisiana Tech.

Solid-state tracking R&D includes both microstrip detectors and silicon drift detectors:

- Long Shaping-time μ-strips
  - Ultra-thin (for momentum resolution and energy-flow)
  - ASIC development at UC Santa Cruz
  - Long (2m) ladders under development at UCSC
- Silicon Drift R&D (Wayne State, Brookhaven)
  - Intrinsically 3-dimensional
  - Proven (STAR VTX detector at RHIC)
  - Longer, thinner sensors; low-power readout
- Mechanical Issues
  - Space frame
  - Interferometeric position monitoring (Michigan)

Vertex Detection

Three groups are working now or plan to start work on vertex detection. The Oregon/Yale/SLAC group is investigating CCDs, as a next step from the success of the 307 Mpixel CCD vertex detector of SLD, VXD3. This studies include:

- Radiation hardness studies
    - removal of SLD VXD3 for analysis
    - spare ladder studies
- Developing new CCD detector prototype
- Studying mechanical issues
- Design readout for X-Band operation

The Oklahoma/Boston/Fermilab group plans to develop a design for a linear collider ASIC for CCD readout, and the Purdue group is planning studies of the mechanical behavior of thin silicon and the development of hybrid silicon pixels for the linear collider.

Calorimetry

Calorimetry R&D is summarized in Table 4.

The calorimeter group has the following test beam plan:

- ECal module (roughly 20 cm x 20 cm x 30 layers)
- HCal module (roughly 1m x 1m x 1m)
- Starting 2004-5; site(s) to be determined
- Goal: Full validation of simulations (GEANT4)

Some additional details of these efforts:

Si/W - SLAC/Oregon/BNL

- Integrated Electronics
    - Analog + digital preliminary design
        - $*$ 0.20x0.25 mm^2/pixel
        - $*$ Full charge and time
        - $*$ Heat looks ok (power pulsing)
- Silicon Detectors
    - Prototype design finalized
        - $*$ 5x5 mm^2 pixels
        - $*$ 6” wafers
    - Vendor order in progress

Colorado’s scintillator tile concept uses an offset type configuration to improve performance. Simulations and detector work is in progress.

Kansas is developing a hybrid scintillator/silicon/tungsten module to provide optimize performance.

RPCs - Argonne/Chicago/BU/FNAL

- Emphasize reliability
- Glass
- Avalanche mode
    - Requires integrated amplification (ASIC)
- Plans for 1 m^3 test beam module underway

GEMs - UT Arlington

- Triple GEM
- GEM foils/prototypes fabricated in Texas
- Simulations underway

Scint. tiles - N. Illinois

- Extensive R&D and simulation progress

Muons

An active group including Fermilab, Northern Illinois, Notre Dame, UC Davis, Wayne State, Rice and UT Austin, is working on a scintillator based muon detector.[1] This effort spans the tasks from simulation of muon detection, to prototype planning. The hardware plan includes:

- Test 16 pixel MAPMT - specification and parameters.
- Test extruded MINOS-style scintillator and fiber.
- Develop prototype modules (2.5m W x 5.0m L) to:
    1. Understand mechanical design/construction issues such as basic scint. Layout, WLS fiber laying, WLS - clear fiber connections, fiber routing, bundling, optical multiplexing, mechanical engineering, etc.
    2. Understand FE electronics, calibration and readout specifications.
    3. Understand safety, testing, and QA procedures.
    4. Implement cosmic ray tests and eventually beam tests.
    5. Make detailed cost estimates for a scintillator-based muon system.

Beamline Instrumentation

A very active group is working on beam-line instrumentation in North America. The high priority items are:

- dL/dE analysis
    - complete analysis to extract both tail and core
    - understand external inputs (asymmetries, offsets)
    - possible to extract correlations (energy, polarization)?

Ecal	Silicon/W Scint/Si/W hybrid Scint tile/W	SLAC/Oregon/BNL Kansas Colorado	Designs and prototyping Initial ideas Ideas under study
Hcal	Digital - Scint. Tiles Digital - RPCs Digital - GEMs	N. Illinois Argonne/Chicago/BU/FNAL UT Arlington	Designs and prototyping Designs and prototyping Initial designs and prototyping

Table 4: Calorimeter Detector R&D in North America

- Extraction line studies
  - expected distributions with disrupted beam
  - expected backgrounds at detectors
- Forward Tracking/Calorimetry
  - Realistic conceptual design for NLC detector
  - Expected systematics eg: alignment
- Beam Energy Width
  - Understand precision of beam-based techniques
  - Possible with extraction line energy spectrometer based on SLD approach of Wire Imaging Synchrotron Radiation Detectors (WISRD)

The ongoing R&D work including the following

- Luminosity
  - dL/dE analysis (SLAC, Wayne St.)
  - Beamstrahlung Monitor (Wayne St.)
  - Pair monitor (Hawaii, in collab. with Tohoku)
  - Forward calorimeter (Iowa St.)
- Energy
  - WISRD spectrometer (UMass, Oregon)
  - BPM spectrometer (Notre Dame)
- Polarization
  - x-line simulations (SLAC, Tufts)
  - Quartz fiber calorimter (Iowa, Tennessee)

There are many important topics uncovered.

Testbeams

Test beams will be required to develop the detectors needed for the linear collider. We must begin now to plan for these beams. An assessment is underway across the regions. Some understanding of these needs is being to develop. Table 5 summarizes the known needs at the present time.

Accelerator R&D

Within the US there is a large interest within the university community in working on linear collider accelerator R&D. This is now funded by DOE at roughly the same level as the linear collider detector R&D and a similar level of support is being considered at NSF.

R&D ON THE JLC DETECTOR

The JLC strategy for choice of technologies in the baseline R&D has been taken with two principles: 1.) there will be no "proof-of-principle" R&D, and 2.) the detector must be constructible within an affordable budget.

The overall layout of the JLC Detector is shown in Figure 12 in the 3T field configuration.

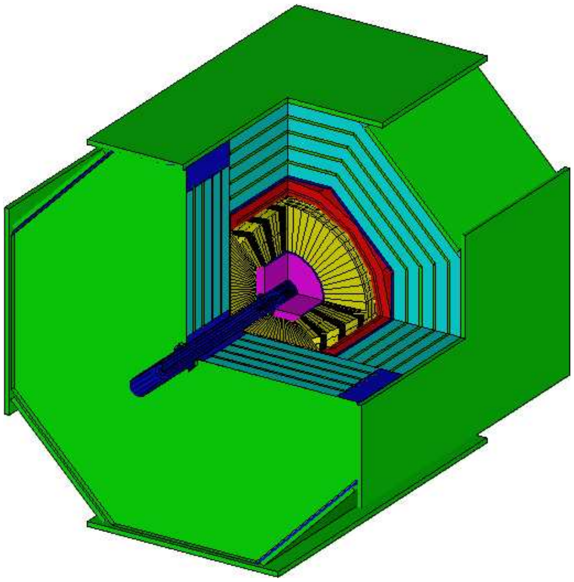

Figure 12: GEANT drawing of the baseline JLC Detector for 3 Tesla.

There is progress in several areas of the detector. In each, we list below the work that is completed, or nearly so, and the work that is in progress, or yet to do.

	Group	Apparatus	Beam Conditions	When/Where
1	TESLA/CALICE J.-C. Brient/P. Dauncy et al	E_Cal/H_Cal E-flow Tests	e,μ,π,p e 1-100 GeV	Mid 2004 - 2005 Fermilab/Protvino? Setup; DESY/CERN Fermilab/Protvino?
2	JLC-Cal - Y. Fujii et al	EM/H Cal Prototypes	e,μ,π,p 1-200 GeV	KEK/2004 US/Europe 2004-8
3	LC- Cal - R. Frey et al	E_Cal H_Cal Prototypes	e to 10 GeV e,μ,π,p $\rightarrow$ 120	E_cal at SLAC '04; E & H_Cal @ FNAL?
4	Digital H_Cal - Argonne, NIU, UTA, et al	H-Cal Prototypes	e,μ,π,p $\rightarrow$ 120	Fermilab - 2005-'06
5	IP Instrumentation Woods/Torrence et al	Gas C counter/cal Quartz fiber cal Sec. Emission det. W. angle, vis light beamstrahlung Synchrotron rad BPM E spectro	e/γ to 100 GeV; LINX for beamstrahlung; Polarized e's	Various
6	IP Instr and Calorimetry Onel/Winn et al	Compton polar. w/ quartz fiber cal; Sec. Emission det. C compensated cal	e,π, p $\rightarrow$ 120 $<$ 20, $<$ 300 GeV	Fermilab CERN PS & SPS
7	Tile/fiber Tests R. Ruchti	Detector prototypes, timing,	e,μ,π 10 - 100 GeV	Fermilab
8	Muon Prototype Detectors TESLA/ALC	RPCs and Scintillator based	e's 50-750 MeV e,μ,π $\rightarrow$ 120GeV	Frascati 2004 Fermilab 2005

Table 5: Test Beam Requirements (incomplete list).

Vertex Detector

- done or finishing soon:
  1. excellent spatial resolution (see Figure 13);
  2. room-temperature operation (good S/N by Multi-Pinned Phase operation);
  3. radiation hardness measurement : ^{90}Sr, ^{252}Cf, electron-beam irradiation; analysis is underway.
- in progress or to do:
  1. CTI improvement: two-phase clocking, thermal charge injection, notch structure (see Figure 14);
  2. fast readout : test-board fabrication in progress ;
  3. thinned CCD (20micrometer): flatness, stability, reproducibility;
  4. precise estimation of background by a full simulation with detailed beamline components.

Intermediate Tracker

- in progress or to do:
  1. Si-sensor fabrication and test-module construction;
  2. Simulation study of VTX-IT-CT combined tracking (see Figure 15).

Central Tracker

- done or finishing soon:
  1. spatial resolution;

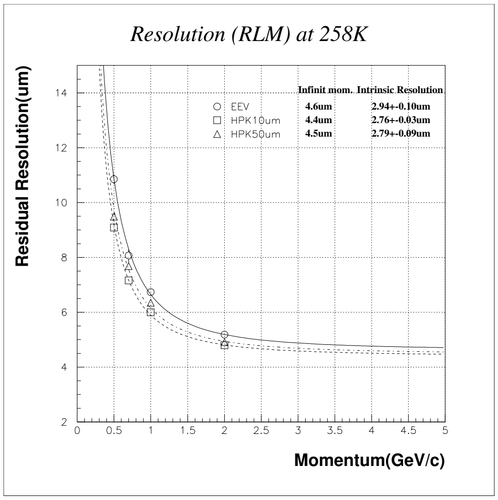

Figure 13: Position resolution of CCD test module obtained with minimum-ionizing pions at KEK $pi2$ testbeam measurement. Intrinsic resolutions, after subtraction of multiple-scattering effects, are written as insight of the figure.

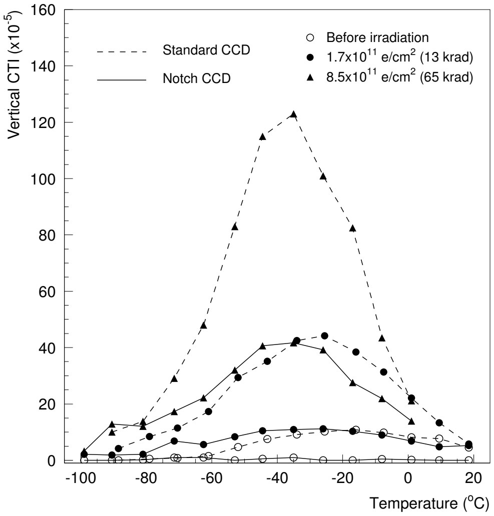

Figure 14: Charge-Transfer Inefficiency of CCDs. Dashed lines are for standard CCD, while solid lines are for 'notched-structure' CCD. Notched structure improves CTI significantly. Notched structure has small deeper well to concentrate charge in a well.

2. effect of gas contamination;
3. Lorentz angle measurement;
4. dE/dx measurement;
5. positive-ion space-charge effect (see Figure 16).

- in progress or to do:
  1. two-track separation performance with a test chamber using parallel laser beam (see Figure 17);
  2. z-measurement with charge division;
  3. solve creeping of aluminum wire;
  4. full-simulation study on Pt resolution;
  5. bunch-tagging capability and its impact on physics sensitivity.

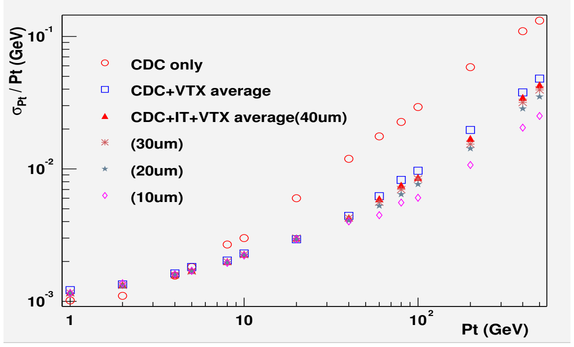

Figure 15: Single-track Pt-resolution (full-simulation) compared for three tracking cases.

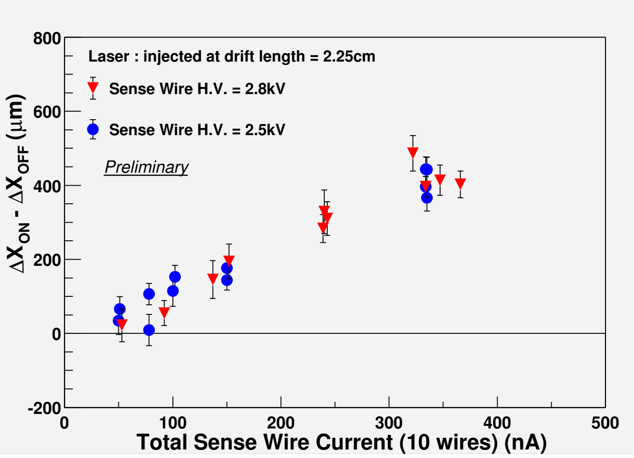

Figure 16: Effect of drift-field deformation caused by positive-ions on position measurement. For higher beam intensity (higher sesne current) measured position shifts. However in the actual operation, inter-train time is long enough to sweep out all the positive ions.

Calorimeter

- done or finishing soon:
  1. hardware compensation, energy response linearity, energy resolution (stochastic term);
  2. machine-ability of tiny tiles, assemble-ability;
  3. performance of WLS-readout shower-position detector.
- in progress or to do:
  1. granularity optimization with a full simulation;

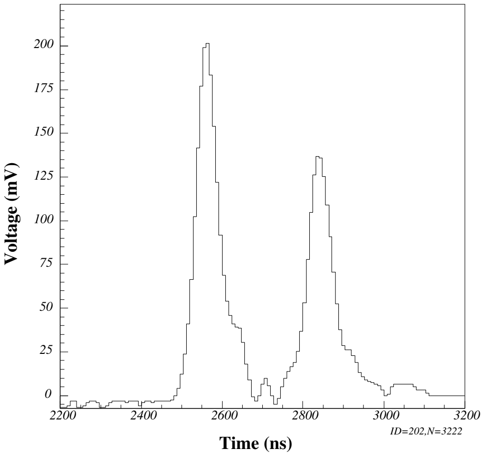

Figure 17: Sense-wire FADC spectrum when two parallel laser tracks are injected into a test chamber with distance of 2.2mm. 2mm-separation is assured.

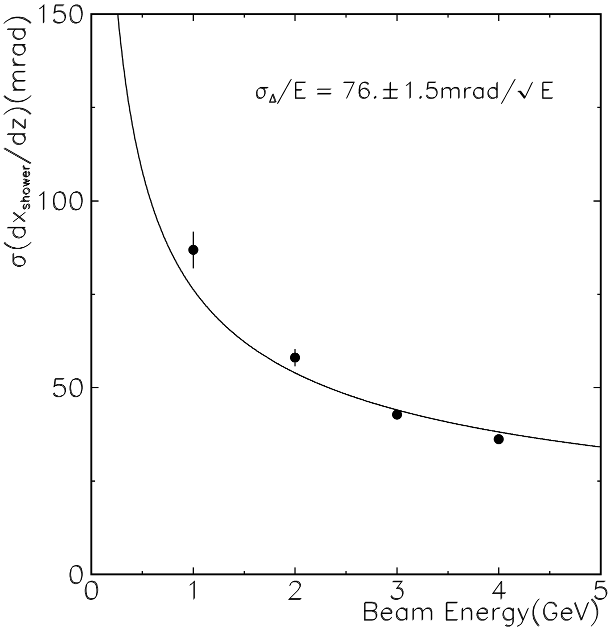

Figure 18: Shower axis angular resolution (preliminary) of a scintillator-strip-array EMcal obtained by a testbeam measurement at KEK. Strip width is 1cm, and the module has 6 superlayers (17 radiation length).

2. photon yield and non-uniformity improvement for conventional tile/fiber EMcal;
3. performance study of strip-array EMcal : beamtest, simulation, ghost-rejection (see Figure 18);
4. shower-position detector with directly-mounted APD-readout;
5. photon detectors (multi-channel HPD/HAPD, EBCCD etc.).

Muon System

There is no effort on the muon system for the JLC Detector.

CONCLUSION

The Detector R&D underway in the different regions of the world shows there is no unique solution, and differing optimizations can lead to quite different detector configurations. The advantages and disadvantages of each approach needs to be confronted with honest assessment and comparison.

REFERENCES

[1] http://www-d0.fnal.gov/~maciel/LCD/awg_lcdmu.html.

[2] Linear Collider Physics Resource Book for Snowmass 2001, http://www.slac.stanford.edu/grp/th/LCBook/, 412-413.