The SiD Detector for the International Linear Collider

Andrew P. White\textsuperscript{1} (for the SiD Consortium)

Department of Physics
University of Texas at Arlington, Arlington, TX 76019, USA

The SiD Detector is one of two validated detector designs for the future International Linear Collider. SiD features a compact, cost-constrained design for precision Higgs couplings determination, and other measurements, and sensitivity to a wide range of possible new phenomena. A robust silicon vertex and tracking system, combined with a 5 Tesla central solenoidal field, provides excellent momentum resolution. The highly granular calorimeter system is optimized for Particle Flow application to achieve very good jet energy resolution over a wide range of energies. Details of the proposed implementation of the SiD subsystems, as driven by the physics requirements, will be given. The shared interaction point, push-pull mechanism, will be described, together with the estimated timeline for construction.

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1 Introduction

Figure 1: The ILC accelerator showing the location of the detectors.

The SiD Detector is one of two detector concepts developed for the future International Linear Collider, to be located in Japan at the proposed Kitakami site. The ILC accelerator is shown in Fig. 1.

The SiD detector is designed for a comprehensive program of $e^+e^-$ physics ranging from percent-level measurement of Higgs boson couplings to precision top quark studies, to searches for new physics such as supersymmetry. The detector requirements to address this physics program are given in Table 1. Many of the Higgs processes require excellent jet energy performance which derives from the design and performance of the tracking and calorimeter systems together with an efficient particle-flow algorithm. The Higgs recoil mass measurement requires excellent charged particle momentum resolution, while Higgs branching fraction measurements for heavy flavors rely on a precision vertex detector. Finally, searches for new phenomena require a hermetic design.

2 The SiD Detector Concept Design

SiD is a compact, cost-constrained detector designed to make precision measurements and be sensitive to a wide range of new phenomena. The compact design is achieved by the use of a high precision silicon vertexing and tracking system in combination with a 5 Tesla solenoidal magnetic field. The vertexing and tracking system offers excellent charged particle momentum resolution and is live for single bunch crossings. The calorimetry is optimized for jet energy resolution, based on a particle flow (PFA) approach, with tracking calorimeters, compact showers in the electromagnetic section, and highly segmented, longitudinally and transversely, electromagnetic and hadronic systems. The iron flux return and muon identifier is a component of SiD self-shielding.
Table 1: Detector performance needed for key ILC physics measurements.

| Physics Process | Measured Quantity | Critical Physical System | Required Magnitude Performance |
|-----------------|-------------------|--------------------------|-------------------------------|
| Zhh             | Triple Higgs coupling | Tracker                  | Jet Energy                    |
| Zh → q̄q̄b̄     | Higgs mass         | and                      | and Resolution                |
| Zh → ZWW⁺⁻     | B(h → WW⁺⁻)        | Calorimeter              | ΔE/E                          |
|                 |                   |                          | 3% to 4%                      |
| νσW⁺⁻W⁻⁻⁻⁻     | σ(e⁺e⁻ → νσW⁺⁻W⁻⁻⁻⁻) |                          |                               |
| Zh → ℓ⁺⁻ℓ⁻X    | Higgs recoil mass  | µ detector               | Charged particle              |
| μ⁺⁻μ⁻⁻⁻⁻(γ)    | Luminosity weighted Ecm | Tracker                  | Momentum Resolution           |
| Zh + hνσ → μ⁺⁻µ⁻⁻⁻⁻ | BR(h → μ⁺⁻µ⁻⁻⁻⁻) |                          | 5 × 10⁻⁵(GeV/c)⁻¹             |
| Zh, h → bb, cc, bb, gg | Higgs branching fractions | Vertex                  | Impact parameter              |
|                 |                   |                          | 5μm⊕                         |
| SUSY, eg. ̃µ decay | ̃µ mass           | Calorimeter              | Hermeticity                   |
|                 |                   |                          | 10μm/p(GeV/c)sin³/2θ          |

The complete detector system is designed for push-pull operation. The main elements of the SiD detector are shown in Fig. 2.

3 SiD Vertexing and Tracking

The SiD vertex detector, Fig. 3 (left), is an all-silicon system consisting of five barrel layers, four disk layers, and three additional small pixel disks in the forward region. The carbon fiber support structure is connected to the beam tube in four places.

Various technologies are being considered for the vertex detector, ranging from standard silicon diode pixels, through monolithic active pixels (as in the Chronopix design), to vertically integrated 3-dimensional structures. Power management for the vertex detector will take advantage of the ILC beam time structure to use pulsed power, and will use DC-DC conversion to avoid the needed for high mass cables that would compromise the otherwise excellent low material profile.

The main tracker is also an all-silicon system with the cylindrical barrel layers closed at the ends by conical, annular disks, as shown in Fig. 3 (right).

The main tracker layers are instrumented with silicon microstrip tiles read out via the KPiX ASIC which features a four-deep pipeline and single bunch time stamping with readout occurring between bunch trains. Power pulsing and DC-DC conversion allows the use of gas cooling and cable mass reduction.

Overall for the tracking system, better than 20% of a radiation length is achieved.
over the angular range to within 10 degrees of the beam direction. A tracking efficiency of at least 95% is achieved over a similar angular range for charged particles with momenta above 1 GeV. The transverse momentum resolution for single muons is shown in Fig. 4 which, for central tracks, exceeds the requirement in Table 4.

4 Calorimetry

SiD calorimetry is designed for the particle plow approach to improving jet energy resolution. The goal is to achieve 3% or better jet energy resolution for jets above 100 GeV. For a PFA the tracker and calorimeter must work together to ensure efficient and effective association of charged tracks with the correct energy deposits in the calorimeter. This implies the need for a high degree of transverse and longitudinal segmentation in the calorimeters. The Moliere radius for the electromagnetic
Figure 4: Normalized transverse momentum resolution for single muons in SiD.

(a) Components of the SiD calorimeter system: purple - hadron calorimeter; green - electromagnetic calorimeter.

(b) Mechanics and components of the SiD electromagnetic calorimeter.

Figure 5: SiD Calorimeter system and detail of electromagnetic calorimeter.

calorimeter should be minimized to facilitate the separation of charged tracks and electromagnetic showers. Naturally, the entire calorimeter system is located inside the volume of the solenoid - which, however, imposes limitations on radial dimensions due to cost considerations. The main elements of the calorimeter system are shown in Fig. 5 (a).

4.1 Electromagnetic calorimeter

In addition to supporting the PFA requirements described above, the ECAL must allow precise measurement of electrons and positrons from Bhabha scattering for determination of electroweak couplings and for a component of the measurement of the luminosity spectrum. The ECAL should also provide for efficient detection and measurement of photons and pizero, for contributions to the jet energy resolution
and for reconstruction of $\tau$ decays. The ECAL baseline design [3] features tungsten absorber plates and highly segmented silicon sensor layers. The main elements of the design are shown in Fig. 5(b).

Each silicon sensor is divided into 1024 pixels, read out by one KPiX ASIC [4]. Each ECAL layer features an aggressive design with only 1.25 mm gap between successive tungsten plates - including the sensor, KPiX, flex cables and a passive cooling system. A nine-layer prototype of the ECAL has been tested and single and multiple electron tracks successfully recorded [3]. There also is a MAPS (Monolithic Active Pixel) design for the ECAL, which has very fine, 50×50 micronsquare, silicon pixels, for which first generation sensors have been tested.

### 4.2 Hadron calorimeter

The HCAL is designed for efficient and unambiguous identification of energy deposits by charged particles, their association with the related tracks in the tracking system, and the measurement of the energies of neutral particles. Within the PFA approach, these functions demand fine transverse and longitudinal segmentation, with the requirement (for the barrel sections) to keep the active layer thickness to a minimum to control the cost of the radially external solenoid.

The baseline technology for the HCAL is resistive plate chambers (RPC) with steel absorber plates [5]. The basic RPC design is shown in Fig. 6(a).

The baseline design has been implemented in a 38-layer prototype with transverse size $1 \times 1$ m$^2$, large enough to contain hadronic showers. Fig. 6(b) shows several examples of hadron showers, and a single muon track, recorded in the prototype which had $1 \times 1$ cm$^2$ readout pads. Several other technologies are also being developed and considered for the SiD HCAL: Scintillator tiles, GEM’s (both foils and ThickGem), Micromegas, and variations on the RPC approach. Fig. 7 shows an example: a
1×1 m² active layer of scintillator tiles with SiPM readout.

Figure 7: Active layer from the scintillating tile-SiPM approach to the SiD HCAL.

4.3 Forward Calorimetry

Fig. 8 shows the recently updated forward calorimeter and luminosity calorimeter layout with the new common L* agreed by SiD and ILD. The LumiCal will use small angle Bhabha scattering to determine the integrated luminosity to better than one part per mil. The BeamCal will provide an instantaneous measurement of the luminosity using beamstrahlung pairs, and will provide small-angle coverage for physics searches.

5 Muon System and Flux Return

The baseline technology for the muon system is long scintillator strips with wavelength shifting fibers and SiPM readout. The roles of the muon system are to identify muons from the interaction point efficiently, and, as a tail-catcher, to flag possible shower leakage through the superconducting solenoid as a part of the particle flow algorithm input. Fig. 9 (a) shows prototype long strips and fibers under development. The steel of the muon system acts as the flux return for the magnetic field from the superconducting solenoid. There is a local site requirement of a maximum of 50 Gauss at 15 m from the main detector axis. Fig. 9 (b) shows a recent design of the
muon steel, with a 30 degree angle between the barrel and endcap steel. This design limits the fringe field and satisfies the 50 Gauss requirement.

6 Installation

The single interaction region of the ILC requires a sharing between the two detector concepts in a push-pull arrangement as shown in Fig. [10]. An assembly and installation procedure has been created. It is estimated to take a period of eight years to complete.

7 Summary

The design of the SiD Detector Concept has been presented, with details of sub-systems. Physics studies with this design have shown that superb performance is expected on the full range of ILC physics. Current detector development topics include a third generation Chronopix and advanced 3-D for the vertex detector, a new silicon sensor for the ECAL, engineering studies for a full-size scintillator-steel HCAL module, and overall optimization of the detector design. The SiD Consortium remains open to new colleagues and to creative input to further optimize or improve the detector design.
(a) Muon system prototype with long scintillator strips with embedded wavelength shifting fibers.

(b) New design of the SiD flux return steel.

Figure 9: Muon system steel and flux return, and scintillator prototype.

References

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Figure 10: The SiD Detector, on the beam axis, and the ILD Detector in the push-pull configuration. The more compact design of the SiD Detector results in a deeper platform as shown in black.