SiD LOI Snowmass 2021

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The SiD Detector is one of two validated detector designs for the future International Linear Collider (ILC). SiD features a compact, cost-constrained design for precision Higgs and other measurements, and sensitivity to a wide range of possible new phenomena. A robust silicon vertex and tracking system, combined with a 5 T central solenoidal field, provides excellent momentum resolution. The highly granular calorimeter system is optimized for Particle Flow (PFA) to achieve an excellent jet energy resolution over a wide range of energies. This paper gives an overview of the main features of the SiD design, areas for further R&D, and opportunities for engagement in developing the SiD concept during and beyond Snowmass 2021.

I. Introduction

The SiD detector is a general-purpose experiment designed to perform precision measurements at the ILC. It satisfies the challenging detector requirements resulting from the full range of ILC physics processes. SiD is based on the paradigm of particle flow, an algorithm by which the reconstruction of both charged and neutral particles is accomplished by an optimized combination of tracking and calorimetry. The SiD detector is a compact detector based on a powerful silicon pixel vertex detector, silicon tracking, silicon-tungsten electromagnetic calorimetry, and highly segmented hadronic calorimetry. SiD also incorporates a high-field solenoid, iron flux return, and a muon identification system. The use of silicon sensors in the vertex, tracking, and calorimetry enables a unique integrated tracking system ideally suited to particle flow.

II. The Tracking system

The tracking system is a key element of the SiD detector concept. The particle flow algorithm requires excellent tracking with superb efficiency and two-particle separation. The requirements for precision measurements, in particular in the Higgs sector, place high demands on the momentum resolution.

Highly efficient charged particle tracking is achieved using silicon-pixel Vertex detector and main tracker to recognize and measure prompt tracks, in conjunction with the ECAL, which can identify short track stubs in its first few layers to catch tracks arising from secondary decays of long-lived particles. With the choice of a 5 T solenoidal magnetic field, in part chosen to control the e^+e^--pair background, the design allows for a compact tracker design.

The SiD vertex detector uses a barrel and disk layout with five silicon pixel layers in the barrel and four in the disks with a pixel size of $20 \times 20\ \mu\text{m}^2$. In addition, there are three silicon pixel disks at a larger distance from the interaction point to provide uniform coverage for the transition region between the vertex detector and the outer tracker. This configuration provides for very good hermeticity with uniform coverage and guarantees excellent charged-track pattern recognition capability and impact parameter resolution over the full solid angle. Opportunities exist for design optimization, sensor development, and mechanical and cooling implementation.

The main tracker baseline uses silicon-strip sensors arrayed in five nested cylinders in the central region and four double-layer disks using following a conical surface with an angle of 5 degrees with respect to the normal to the beam-pipe in each of the end-cap regions. The geometry of the end-caps minimizes the material budget to enhance forward tracking. The tracker sensors have a size of approximately 10×10 cm^2 with a strip pitch of 25 µm. The sensor uses a hybrid-less design with two KPiX readout ASICs directly bump-bonded to the sensor. The charged track momentum resolution will be better than $\delta(1/p_T) = 5 \times 10^{-5}/(\text{GeV}/c)$ for high momentum tracks with coverage down to polar angles of 10 degrees. As well as optimizing the silicon strip design, there is a growing interest in developing a proposed MAPS-based tracking design.

III. Calorimetry

The SiD baseline design incorporates the elements needed to successfully implement the PFA approach, imposing a number of basic requirements on the calorimetry. The central calorimeter system must be contained within the solenoid in order to reliably associate tracks to energy deposits. The electromagnetic (ECAL) and hadronic (HCAL) sections must have imaging capabilities that allow both efficient track-following and correct assignment of energy clusters to tracks. These requirements imply fine longitudinal and transverse segmentation. In order to ensure that no significant amount of energy can escape detection, the calorimetry must extend down to small angles with respect to the beam-pipe and must be sufficiently deep to prevent significant energy leakage. The calorimeter system must also be designed for the highest-energy collisions envisaged. SiD's reliance on particle flow calorimetry to obtain a jet energy resolution of $\sim$3% demands a highly segmented electromagnetic calorimeter. It also calls for a small lateral electromagnetic shower size, by minimizing the Moliere radius to efficiently separate photons, electrons and charged hadrons. The SiD ECAL design employs thirty silicon longitudinal layers, the first twenty each with a 2.50 mm tungsten alloy absorber thickness and 1.25 mm readout gaps, and the last ten with 5.00 mm tungsten alloy. The total depth is 26 radiation lengths, providing good containment of electromagnetic showers. The baseline design employs tiled, large, commercially produced silicon sensors. The sensors are segmented into pixels that are individually read out over the full range of charge depositions. The complete electronics for the pixels is contained in a single chip, the KPiX ASIC, which is bump bonded to the wafer. The low beam-crossing duty cycle (10^{-3}) allows reducing the heat load using power pulsing, thus allowing passive thermal management within the ECAL modules. Results have been obtained from an initial 9-layer prototype and further R&D is foreseen on a full-depth stack.

The SiD HCAL has a depth of 4.5 nuclear interaction lengths, consisting of alternating steel plates and active layers. The baseline choice for the active layers is scintillator tiles read out via silicon photomultipliers. For this approach SiD is closely following the analog hadron calorimeter developments within the CALICE collaboration. In this context, the simulated HCAL energy resolution has been shown to reproduce well the results from the CALICE AHCAL prototype module exposed to pion beams. An initial, conceptual mechanical design has been developed, and further work is needed on all aspects of the design.

Two special calorimeters are foreseen in the very forward region: LumiCal for a precise luminosity measurement, and BeamCal for the fast estimation of the collision parameters and tagging of forward-scattered beam particles. LumiCal and BeamCal are making both use of semiconductor-tungsten technology. The BeamCal is placed just in front of the final focus quadrupole and LumiCal is aligned with the electromagnetic calorimeter end-cap.

IV. Solenoid and Muon systems

The SiD superconducting solenoid is based on the CMS solenoid design philosophy and construction techniques, using a slightly modified CMS conductor as its baseline design. The flux-return yoke is instrumented with position sensitive detectors to serve as both a muon filter and a tail catcher. The total area to be instrumented is very significant – several thousand square meters. Technologies that lend themselves to low-cost large-area detectors are therefore under investigation. The SiD baseline design choice is using extruded scintillator readout with wavelength shifting fiber and SiPMs.

V. Machine Detector Interface

A time-efficient implementation of the push-pull model (two detectors share one interaction region) of operation foreseen for the ILC sets specific requirements and challenges for many detector and machine systems, in particular the interaction region (IR) magnets, the cryogenics, the alignment system, the beam-line shielding, the detector design and the overall integration. The minimal functional requirements and interface specifications for the push-pull IR have been successfully developed and published. All further IR design work on both the detectors and machine sides are constrained by these specifications.

VI. Software and Physics

The SiD baseline design has been validated in detailed studies with a Geant4 simulation and a realistic reconstruction, which has been documented in the SiD part of the ILC technical design report. For the Snowmass process, we provide DELPHES samples that have been compared against the detailed simulation. These should serve as a starting point for studying e^+e^-physics with SiD. We look forward to discussing new ideas for detector design and plans for physics studies.

VII. Summary

A design for the SiD Detector for the ILC has been presented. This design has been shown to deliver the performance needed by the ILC physics program. However, there are many areas of opportunity for alternative design ideas, detailed design, and subsystem R&D. We warmly invite new colleagues to join us in the SiD design effort as we advance towards a full technical design report for proposal to the ILC.