SiD Status and Plans

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Abstract

Recent work carried out in the SiD Consortium is reported. Results have been obtained with the Chronopix version 3 chip, intended for the SiD vertex detector. A test structure is being produced for KPiXM, a CMOS MAPS approach that could be used for the tracker and electromagnetic calorimeter. Tracker sensors are being tested and a new prototype sensor is being planned. A new effort on tracker support structures has begun and first prototypes produced. New studies of the pair background envelope in the beam pipe have been carried out. Electromagnetic calorimeter testbeam data has been analysed and plans are being developed for a full stack prototype. New comprehensive studies of high-rate backgrounds and muons from the beam delivery system have been carried out to determine aspects of the forward region layout. Work has started on alignment and calibration strategies; and progress has been made on a new simulation and reconstruction framework for SiD.
1 Introduction

SiD [1,2] is a compact, cost-constrained, general-purpose detector proposed for the International Linear Collider: a future e⁺e⁻ collider with baseline energy of √s = 500 GeV and potential to operate up to √s = 1 TeV. This contribution reports the SiD Consortium’s R&D and software developments since the 2015 International Workshop on Future Linear Colliders.

2 SiD Overview

SiD is designed to make precision measurements and to be sensitive to a wide range of new phenomena. The detector consists of several subsystems. The sensitive layers of the vertexing and tracking system are entirely silicon and provide excellent momentum resolution and single bunch-crossing time-stamping. Highly segmented calorimeters optimized for particle flow sit inside a solenoid of inner radius 2.6 m that provides a 5 T B-field. The coil is surrounded by an iron flux return that incorporates muon chambers, and the complete assembly is mounted on a platform designed for rapid push-pull operation. Further details on the subsystems and on recent work are given in the following sections.

3 Vertexing and Tracking

The vertex detector consists of five short barrel layers starting at radius r = 1.4 cm, and five disks. The required hit resolution is better than 3 μm and the system needs to provide single-bunch timing resolution, and keep within a material budget of around 0.1% X₀ per layer, and a power budget of less than 130 μW/mm². As the vertex detector will be one of the final systems to be installed, the technology choice for implementation can be made later; options include ‘standard’ silicon diode pixels, monolithic designs such as Chronopix, vertically integrated chips, or high-voltage CMOS.

The current baseline readout for the vertex detector is the Chronopix chip. Its concept has been proven through a series of three prototypes [3]. The first version demonstrated 300 ns timestamping, sparse readout, and pulsed powering; the second version demonstrated NMOS electronics with acceptable power consumption and comparator offset calibration; and the third, current, version has six sensor options to address a large sensor capacitance that was observed in version 2 and appears now to be solved. Cross-talk issues have also been addressed by separating analogue and digital power and adding a decoupling capacitor. Ongoing work is to fully characterise the sensor operation: sensor efficiency for MIPs and radiation hardness measurements are in progress with the prototype 3 chips.

The silicon strip tracker extends to r = 1.25 m and consists of five barrel layers and four disks of 25 μm pitch strips with 50 μm readout. The system is gas-cooled and has a total material budget of less than 20% X₀ in the active region.

The current baseline readout for the tracker uses the KPiX ASIC [4], bump-bonded to the module. There is also ongoing development work on KPiXM, a CMOS MAPS approach where the sensors and front-end electronics are integrated on the same substrate. This has potential for a lower material budget, smaller pixel size that is not limited by bump-bonding, and lower cost through implementation in standard commercial technologies. A test structure is currently being produced in 150 nm technology, using a high-resistivity substrate thinned to 150 μm. Several variants of active and passive pixels of 40 × 500 μm² are included. A variant with larger 1000 × 1000 μm² pixels could be used for the SiD electromagnetic calorimeter.

There has been progress on the tracker sensors. A previous Hamamatsu prototype was found to be damaged when undergoing wirebonding. Recently, agreement has been reached to produce a new prototype with increased oxide layer thickness between the two metal layers to address this problem, as well as under-bump metallization. The Consortium is moving towards a full prototype test consisting of sensor, KPiX readout, and attached cables.
Furthermore, there has been new effort on tracker support structures by groups in the UK. This aims to build structures that integrate services and cooling, with lengths of several metres and material budget less than 1% \(X_0\), using carbon fibre reinforced polymer box channels. Services can be co-cured into the structure, and adjacent box channels linked by tongue-and-groove joints. Tracker modules would sit on both sides of the resulting hoop structures. FEA studies have been done, and first prototypes produced.

Finally, there have been updated studies of the pair background envelope in the beampipe. These are described in detail elsewhere in these proceedings [5]; in summary: with the current beampipe design, only around 0.45% of all particles leave tracks outside the beampipe. A reduction in the beampipe radius of up to 2 mm could therefore be considered, and even the addition of an additional vertex detector layer; however, this would require further studies of synchrotron radiation and flavour tagging performance.

4 Calorimetry

A highly granular ‘imaging’ calorimeter is essential for the ILC physics programme as an integral part of the particle flow reconstruction approach.

The baseline design for the electromagnetic calorimeter consists of 20 thin and 10 thick tungsten layers interspersed with silicon sensitive layers. The silicon sensors are hexagonal arrays of 1024 pads, each 13 mm\(^2\), bump-bonded to a KPiX ASIC. Experience so far with test sensors has shown that bump bonding to sensors with aluminium pads can be very difficult; under-bump metallization should help with that. In addition, traces in the metal-2 layer from pixels to the pad array that run over other pixels have been observed to cause parasitic capacitance and cross-talk; in an updated design, a fixed potential trace in the metal-1 layer shields the signal traces from the pixels. New prototypes with KPiX attached are currently under preparation for cable attachment.

A nine-layer prototype corresponding to around 6\(X_0\) has been tested in a 12 GeV electron testbeam at SLAC. Details of the analysis are given elsewhere in these proceedings [6], showing good identification of showers that are separated by at least 1 cm in the calorimeter. Plans are being developed for a full stack prototype.

The Detector Baseline Design for the hadronic calorimeter consisted of digital readout using resistive plate chambers with 1 \(\times\) 1 cm\(^2\) tiles. Following collaboration-wide review, the baseline technology has been updated to analogue readout using scintillator and silicon photomultipliers, with 3 \(\times\) 3 cm\(^2\) tiles. The hadronic calorimeter is composed of 40 layers. Work is ongoing to compare single-particle energy resolutions with CALICE testbeam results, and further work on the mechanical design is foreseen following the rebaselining.

5 Solenoid and Muon System

A recent redesign has introduced a 30\(^\circ\) junction between the barrel and doors of the return yoke. This has the benefit of more efficient flux return and lower stray fields, and also allowing easier transport and handling by redistributing the material between the barrel and doors.

The SiD baseline has the muon system consisting of long scintillator strips with wavelength-shifting fibre and silicon photomultiplier readout; this is a consistent extension of the updated baseline hadronic calorimeter technology. Further optimization of the strip dimensions and number of layers will be carried out. Since the Detector Baseline Document, the yoke and muon system has been updated from an eightfold to twelve-fold geometry to match the calorimeters.
6 Forward Region Layout

A recent comprehensive set of studies considering high cross-section processes such as pair-production arising from beam-beam interactions, Bhabha scattering, and two-photon processes, has addressed several aspects of the forward region layout. These are described in detail in a dedicated report [7].

Systematic studies were done of the shape of the BeamCal and the effect of an anti-DID (Detector-Integrated Dipole) on the inner detector occupancy. Studies were carried out using the $\sqrt{s} = 500$ GeV luminosity upgrade beam parameters in order to be conservative. The vertex detector barrel occupancy was shown to be robust under different BeamCal geometry variants and with or without the anti-DID. Furthermore it was seen that background pairs can arrive as long as microseconds after the beam crossing, which allows the possibility of rejecting them using timing cuts.

The forward calorimeter occupancies were also studied in order to determine the necessary buffer depth. With a depth of 4 buffers, around $10^{-3}$ of hits were lost; with a depth of 6 buffers this was reduced to $10^{-4}$ of hits; however, in order to maintain losses below $10^{-4}$ of hits for the innermost radii, 8 buffers were found to be needed.

Finally, the effect of muons from the beam delivery system was studied, as described elsewhere in these proceedings [8]. Magnetized spoilers are intended to sweep muons from the beam delivery system into the tunnel walls. Full simulation of the detector found the silicon tracker endcap occupancy to be acceptable with these spoilers. However, the electromagnetic calorimeter endcap occupancy was very high; this could be reduced by introducing a magnetized wall in addition to the spoilers.

7 Simulation and Reconstruction

At the 2015 International Workshop on Linear Colliders, SiD decided to implement its simulation in DD4hep [9], and adopt a common reconstruction in order to benefit from shared effort among the different linear collider detector concepts. Since then there has been a lot of progress in implementing the geometry, drivers, and digitizers and developing performance benchmarking tools. Currently, tracking pattern recognition and Pandora particle flow reconstruction are being commissioned.

8 Alignment and Calibration Strategies

Track-based alignment will be essential for high-precision tracking at SiD. Owing to the low cross-sections of relevant processes, there will be limited high-$p_T$ tracks to carry out the alignment. Studies indicate that around 1000 tracks per month per module in the outer tracker will be available during ramp-up in the first year, and SiD has no reason to believe that this would be significantly enhanced by running at $\sqrt{s} = 91$ GeV. Different strategies, such as frequency-scanning interferometry, or modification of the electronics to increase efficiency for cosmic-ray tracks, will be investigated to contribute to the alignment.

9 Outlook

SiD is a compact, capable detector with a well-defined baseline that exceeds the physics requirements. Nonetheless there is ongoing activity in readout, sensors, structures, layout, and simulation and reconstruction as described here. Over the coming year, among other things the SiD Consortium will continue to characterize the Chronopix sensor and new prototypes for KPiXM and a tracker sensor prototype; plans will be developed for a full stack electromagnetic calorimeter prototype; and work will continue on the new simulation and reconstruction chain. New members are welcome to join the SiD Consortium to contribute to this effort in preparation for the technical design phase.
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