# Recent Progress Toward the International Linear Collider


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**Abstract.** The Reference Design Report produced by the ILC Global Design Effort achieves the physics requirements for the 500 GeV electron-positron collider. Detector R&D advances to enable the unique physics potential of the ILC. Progress and plans are summarized.



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## INTRODUCTION

The International Linear Collider (ILC) has a critical role in resolving interpretations of Terascale physics. Recently the ILC Global Design Effort completed the Reference Design Report including a cost estimate. Detector technologies are being advanced to realize the unique ILC physics opportunities. These developments are documented in the four volume Reference Design Report for the 500 GeV electron-positron collider.[1] This paper summarizes recent progress toward the ILC, drawing heavily on these volumes.

## THE PHYSICS GOALS OF THE ILC

The International Linear Collider (ILC) will be a powerful tool for exploring Terascale physics.[2] The success of Twentieth Century particle physics in developing the Standard Model, and in sensitively testing its predictions, has suggested experiments at the Terascale will reveal answers to questions of deep significance. These questions will be probed with the next generation of colliders, beginning with the Large Hadron Collider (LHC). If a Standard Model-like Higgs boson is responsible for electroweak symmetry breaking (EWSB), the mass and width will be measured precisely by the ILC ($\delta M_H \sim 50$ MeV for $M_H = 120$ GeV), the branching ratios for many channels will be measured with few percent uncertainty, the spin and parity will be checked, and self-coupling will be measured. Should alternative EWSB scenarios be the choice of Nature, the ILC has virtual sensitivity to strong coupling up to several TeV, exceeding the reach of the LHC in some scenarios. The ILC is very strong in its access to the slepton, neutralino, and chargino measurements, if the masses permit. The polarized beam capabilities of the ILC are particularly useful for these measurements. Extra dimensions can be probed. Measurements of the top mass (sub-100 MeV precision), the top Yukawa coupling, and the W mass broaden the ILC's physics impact.

Electron-positron collisions provide a highly effective avenue for exploring new physics at the Terascale. Physics measurements are empowered by the knowledge of the constrained initial state of the ILC interaction, including the energy and helicity of the interacting leptons. Furthermore, the interactions are simple processes with comparable cross sections. For example, the Higgsstrahlung process ($e^+e^- \rightarrow ZH$) for $M_H = 120$ GeV at $\sqrt{s} = 500$ GeV, has a cross section that is roughly half the diquark ($e^+e^- \rightarrow$ d d-bar) cross section. With an inclusive trigger and highly polarized beams (80% for electrons, as well as positron polarization), the events are clean and revealing. Detectors should realize powerful flavor tagging, with exquisite vertex detection, and quantitative jet measurements, enabling a precision test of the Higgs boson for Standard Model properties. Discovery of non-Standard Model properties will be possible with precision that goes well beyond the LHC.[2]

Study of the Higgs boson through the Higgstrahlung process provides an important example of the ILC's precision. When the Higgs is produced in association with a Z boson, $e^+e^- \rightarrow ZH$, events can be tagged by reconstruction of the Z, without reference to the decay of the Higgs itself. Even invisible decays of the Higgs are accessible in this way. A precise measurement of the decay modes of the Higgs is possible, and deviations from the Standard Model can be discovered with great sensitivity, without model assumptions.

## THE ILC REFERENCE DESIGN

In August, 2004, the International Committee for Future Accelerators (ICFA) endorsed the recommendation of the Technology Recommendation Panel (ITRP) of superconducting radio-frequency (SCRF) technology for the ILC. Beginning at the 1st International Linear Collider Workshop at KEK, Tsukuba, Japan, in November, 2004, and continuing with the formation of the ILC Global Design Effort (GDE) at the 2nd ILC Workshop at Snowmass, Colorado, USA, in August, 2005, the design of a collider based on 1.3 GHz SCRF accelerating cavities was initiated. At the first GDE meeting at INFN, Frascati, Italy, in December, 2005, a Baseline Configuration Document (BCD) was created. From the BCD, the reference design was developed, and released in 2007 as the ILC Reference Design Report (RDR). The GDE now prepares for an Engineering Design Report (EDR) in 2010.

Building on decades of linear collider R&D, including the construction and operation of the first linear collider, the SLC (SLAC Linear Collider), the technical design and cost estimate of the RDR have a sturdy foundation. The parameters of the ILC RDR are based on specifications set by the physics program.[3] These specifications consider exploration of electroweak symmetry breaking through the Higgs mechanism mediated by scalar Higgs bosons, through strong coupling, or other alternatives.

Studies of supersymmetric states and other new physics, such as extra dimensions, are considered. The initial maximum center of mass energy is $\sqrt{s} = 500\ GeV$, with physics runs possible for any energy between 200 and 500 GeV. Threshold scans are required for mass measurements, with fast changes of the beam energy in small steps.[1] An integrated luminosity of around $500\ fb^{-1}$ within the first four years and about $1000\ fb^{-1}$ during the first phase of operation is required. An electron beam polarization of larger than 80% is mandatory, and positron beam polarization of more than 50% is desirable. The center of mass energy is upgradeable to 1 TeV.

In addition to the standard $e^+e^-$ running at $\sqrt{s} > 200\ GeV$, the ILC offers options that can be realized with reasonable modifications if required by physics. These include the GigaZ mode, and $e^-e^-$, $e^-\gamma$ or $\gamma\ \gamma$ collisions.

The design requirements are achieved by an ILC design with two 11 km super-conducting linacs operating at 31.5 MV/m. 1.3 Ghz SCRF cavities are employed to produce the 1.6 msec RF pulse lengths. A polarized electron source is produced by a photocathode DC gun. A centralized injector includes 6.7 km circumference circular damping rings for 5 GeV electrons and positrons, and an undulator based positron source, driven by a 150 GeV electron beam. A 4.5 km long Beam Delivery System (BDS) brings the two beams into collision at a single interaction region (IR) with a 14 mrad crossing angle. The IR serves two detectors in a push-pull configuration. The design is illustrated in Figure 1. The total footprint is about 31 km long.

The upgrade to $E_{cms}$ = 1 TeV is accomplished by extending the linacs and the beam transport lines from the damping rings by ~11 km each. Certain components in the beam delivery system would need to be replaced.

The nominal beam parameters for the $2\times10^{34}\ cm^{-2}s^{-1}$ design luminosity at $E_{cms}$ = 500 GeV, optimizes trade-offs in accelerator physics and technology challenges. These include: beam instability and kicker hardware constraints in the damping rings; beam current, beam power, and pulse length limitations in the main linacs; emittance preservation requirements in the main linacs and the beam delivery system; and background control and kink instability issues in the interaction region.

It has been common for high-energy accelerators to face unanticipated problems in achieving their design luminosities. Flexibility in operating parameters allows for compensation of poor performance in one area by another area. The ILC design builds in this flexibility by specifying that each subsystem support a range of beam parameters. Examples are bunch populations from $1\times10^{10}$ to $2\times10^{10}$ particles per bunch, number of bunches per train from 1260 to 5340, bunch length from 200 to 500

[1] The capability to collect data at a series of energies around the threshold of a new physical process is unique to an $e^+e^-$ collider. This is an extremely powerful tool for measuring particle masses with high precision and determining particle spins unambiguously. Selecting particular running energies can also boost cross-sections and minimize backgrounds for particular studies.

microns at the IP, and IP beam spot sizes from 474 to 640 nm horizontal and 3.5 to 9.9 nm vertical. The design luminosity is achieved throughout these ranges of parameters.

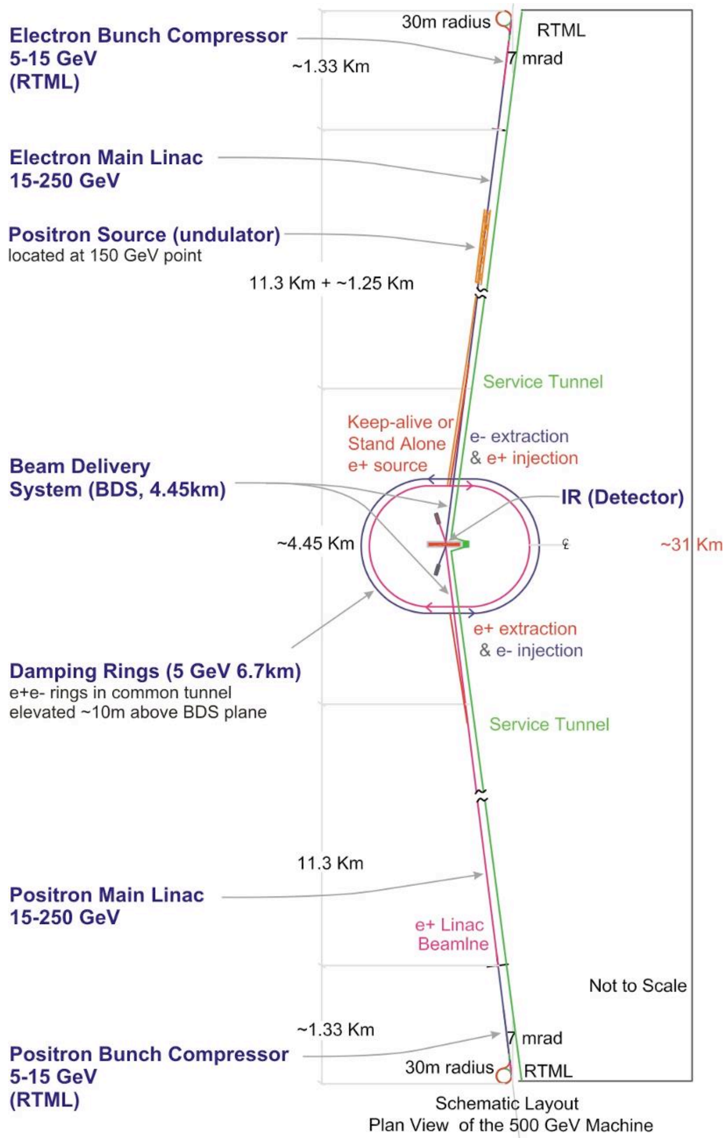


**FIGURE 1. Schematic layout of the ILC complex for 500 GeV CM Energy**

The primary challenge for the ILC electron source is the long one millisecond bunch train. The SLC polarized electron source has already achieved the required polarization, charge, and lifetime. A laser illuminated photocathode produced beam is accelerated to 5 GeV before injection into the damping ring.

The positron source is based on photoproduction by high-energy (~10 MeV) photons generated from a 150 GeV electron beam passing through a 150 meter helical undulator. Electron and positrons are photoproduced in a rotating Ti-alloy target.

Captured positrons are accelerated in stages to 5 GeV before injection into the damping ring. Beamline space has been reserved for an upgrade to >50% polarization.

The 6.7 km long, 5 GeV damping rings reduce the transverse and longitudinal emittances of the beams by five orders of magnitude within 200 msec. The requirements for injection and extraction place high demands on stability and control. The bunch spacing in the damping rings is about 3 nanoseconds. RF systems and superconducting wiggles are located in four of the six straight sections. Principal challenges are control of the electron cloud effect in the positron damping ring, control of the fast ion instability in the electron damping ring, and development of a very fast rise and fall time kicker for single bunch injection and extraction. The plane of the damping rings is elevated by about 10 m above that of the BDS to avoid interference.

The primary cost driver for the ILC complex is the main linacs. Each accelerates from 15 GeV to 250 GeV over 11.5 km. The design average accelerating gradient of 31.5 MV/m is a challenge. Emittance preservation is critical, as is energy stability (0.1% at the IP), and transverse and longitudinal stability. The linacs are formed by three contiguous SCRF cryomodules containing 26 nine-cell cavities. The positron linac contains 278 RF units and the electron linac has 282. Each RF unit has a standalone RF source. The main linac components are housed in two tunnels, an accelerator tunnel and a service tunnel, facilitating maintenance and limiting radiation exposure.

Several multi-cell cavities have met ILC specifications. However, the production mode yield is not yet sufficient. A global, focused effort is underway to advance these capabilities.

The Beam Delivery System (BDS) plays a critical role in achieving the tiny, interacting beam spots at the IP. In addition, it matches the linac beam to the final focus, protects the beamline and detector against mis-guided beams, reduces detector backgrounds by removing beam-halo, measures and monitors key physics parameters such as energy and polarization, and transports spent beams to the main beam dumps. The design handles 500 GeV center-of-mass operation, but is upgradeable to 1 TeV.

The ILC design has a single collision point with a 14 mr crossing angle. Two detectors share the interaction region in a push-pull configuration. Electronics and service platforms are attached and move with each detector. Detector pre-assembly is planned on the surface, with lowering into the IR hall when the hall is ready.

A preliminary cost analysis has been performed for the ILC Reference Design, allowing cost-to-performance optimization before entering into the engineering design phase. Over the past year, a cost reduction of about 25% was achieved through ten significant cost-driven changes that maintained the physics performance goals. The ILC cost estimates have been performed using a "value" costing system, which provides basic agreed-to value costs for components in ILC Units[2], and an estimate of

[2] For this value estimate, 1 ILC Unit = 1 US 2007$ (= 0.83 Euro = 117 Yen).

the *explicit* labor (in person hours) that is required to support the project. The estimates are based on making world-wide tenders (major industrialized nations) using the lowest reasonable price for the required quality. There are three classes of costs: site-specific costs, where a separate estimate was made in each of the three regions; conventional costs for items where there is global capability – here a single cost was determined; costs for specialized high-tech components (e.g. the SCRF linac technology), where industrial studies and engineering estimates were used.

The total estimated value for the shared ILC costs for the Reference Design is 4.87 Billion (ILC Units). In addition, the site specific costs, related to the direct costs to provide the infrastructure required to site the machine, are estimated to be 1.78 Billion (ILC Units). Finally, the explicit labor required to support the construction project is estimated at 22 million person-hours; this includes administration and project management, installation and testing.

## ILC DETECTORS

ILC detectors must ensure optimal scientific outcomes for the experimental program. Experimental conditions at the ILC provide an ideal environment for the precision study of particle production and decay, and offer the unparalleled cleanliness and well-defined initial conditions conducive to recognizing new phenomena. Events are recorded with detectors designed for optimal physics performance without trigger bias. The physics poses challenges, pushing the limits of jet energy resolution, tracker momentum resolution, and vertex impact parameter resolution. Multi jet final states and SUSY searches put a premium on hermeticity and full solid angle coverage. Although benign by LHC standards, the ILC environment poses challenges of its own. Improvements and new readout and sensor technologies are required. The less harsh ILC environment admits designs and technologies not possible at the LHC.

The World Wide Study of Physics and Detectors for Future Linear Electron-positron Colliders[4] has wrestled with these challenges for more than a decade, advancing the detector technologies needed for ILC detectors. Concepts for detectors have evolved[5] with collider progress. The detectors meet the ILC physics demands, and are buildable with technologies within reach. A growing community is involved in refining and optimizing designs, and advancing the technologies. Continued and expanded support of detector R&D and integrated detector studies can lead to full engineering designs, and proof of principle technology demonstrations on the timetable of the ILC Engineering Design Report.

Many interesting ILC physics processes appear in multi-jet final states, often accompanied by charged leptons or missing energy. Precision mass measurements require a jet energy resolution of $\frac{\sigma_{E_{jet}}}{E_{jet}} = \frac{30\%}{\sqrt{E_{jet}}}$ for $E_{jet}$ up to approximately 100 GeV, and $\frac{\sigma_{E_{jet}}}{E_{jet}} \leq 3\%$ beyond, more than a factor of two better than achieved at LEP/SLC. SUSY searches require good missing energy resolution and hermeticity. Excellent lepton identification within jets is critical for W and Z studies, heavy quark decays involving neutrinos, and jet flavor and quark charge tagging. Accurate momentum measurements over the largest possible solid angle are required.

The jet mass resolution appears achievable from an excellent, highly efficient, nearly hermetic tracking system with a finely segmented calorimeter. Charged tracks reconstructed in the tracker are isolated in the calorimeter, and their contributions are removed from the calorimeter energy measurement. This "particle flow" concept has motivated the development of high granularity calorimeters, and highly efficient tracking systems. The main challenge is the separation of neutral and charged contributions within a dense jet environment. Calorimeter granularity requirement of particle flow concept is satisfied with electromagnetic cell sizes of about $1 \times 1$ cm$^2$, and comparable or somewhat larger hadronic cells, while electromagnetic (hadronic) energy resolution of $\sim 15\% / \sqrt{E}$ ($\sim 40\% / \sqrt{E}$) is acceptable.

The ILC momentum resolution specification exceeds the current state of the art. Full solid angle coverage from the beam energy to very low momenta is required for particle flow calorimetry and missing energy measurements. Robust, highly efficient pattern recognition in the presence of backgrounds is demanded with minimal material to preserve lepton ID and high performance calorimetry. "Higgs-strahlung" production in association with a Z allows a precision Higgs mass determination, precision studies of the Higgs branching fractions, measurement of the production cross section and accompanying tests of SM couplings, and searches for invisible Higgs decays. The resolution in the recoil mass from a Z decaying to leptons depends on beam energy accuracy, beam energy spread, and the tracking precision, which needs to be $\frac{\sigma(p_t)}{p_t^2} < 1 \times 10^{-4}\ (GeV/c)^{-1}$. Even better resolution is useful, as the 120 GeV Higgs mass resolution at , $\sqrt{s} = 350\ GeV$ with $500\ fb^{-1}$ goes from 273 MeV to 103 MeV as the resolution improves from $8 \times 10^{-5}\ (GeV/c)^{-1}$ to $2 \times 10^{-5}\ (GeV/c)^{-1}$ (Figure 2 [6]). The tracker is also critical to mass determination of kinematically accessible sleptons and neutralinos, and accurate measurements of the center of mass energy.

Vertex detection identifies heavy particle decay vertices, enabling flavor and charge tagging. Multilayer vertex detection also provides efficient stand-alone pattern recognition, momentum measurement for soft tracks, and seeds for tracks in outer trackers. The ILC physics goals push vertex detector efficiency, angular coverage, and impact parameter resolution beyond the current state of the art, even surpassing the SLD CCD vertex detector.[7] The ILC $e^+e^-$ pairs present a background of up to 100 hits/mm$^2$/train for the innermost detector elements. It is essential to reduce the number of background hits, either by time-slicing the bunch train into pieces of <150 bunch crossings, or by discriminating charged tracks from background. The simultaneous challenges of rapid readout, constrained power budgets, transparency, and high resolution, are being actively addressed by many new technology efforts that reach beyond LHC capabilities due to the low ILC data rates and radiation load.

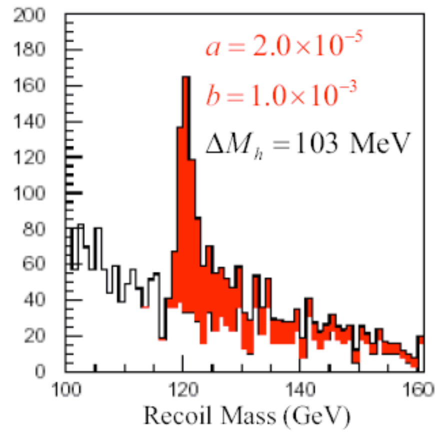


Figure 2. Higgs recoil mass spectra for tracker momentum resolution, $\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$, for 120 GeV Higgs mass, $\sqrt{s} = 350\ GeV$, and $500\ fb^{-1}$.[6]

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The very forward region of the ILC detector will be instrumented with a BeamCal, extending calorimeter hermeticity to small angles. This instrument must veto electrons in the search for new particles in a high radiation and background environment. Measurement of the energy deposited by beamstrahlung pairs and photons in the BeamCal and GamCal allow a bunch-by-bunch luminosity measurement and an intra-train luminosity optimization. The absorbed radiation dose is up to 10 MGy per year near the beampipe.

Polarimetry and beam energy spectrometry must reach new levels of systematic understanding, with polarization measured to 0.1% and beam energy measured to 200 ppm. High-field superconducting solenoid designs must be refined, with development of new conductors, and accommodating Dipole-In-Detector and Solenoid compensation, field uniformity, and push-pull capabilities. Muon detectors must be developed.

Detector system integration demands serious engineering and design. Stable, adjustable, vibration free support of the final quadrupoles, and the fragile beampipe with its massive masking is needed. The detectors will be required to move on and off beamline quickly and reproducibly ("push-pull"). The detectors must be calibrated, aligned, and accessed, without compromising performance.

Four detector concepts are being studied as candidate detectors for the ILC experimental program. These represent contrasting and complementary approaches and technology choices. Each concept is designed with an inner vertex detector, a tracking system employing either a gaseous TPC or silicon, a calorimeter to reconstruct jets, a muon system, a high field superconducting solenoid, and a forward system of tracking and calorimetry. Table 1 presents some of the key parameters of each of the four detector concepts. GLD, LDC, and SiD employ particle flow for jet energy measurements. SiD has the strongest magnetic field, and the smallest radius, while LDC and GLD rely on smaller fields with larger tracking radii. The $4^{th}$ concept uses dual-readout calorimetry and a novel outer muon system.

The Silicon Detector (SiD) illustrates optimization of design choices. SiD has been conceived as a state of the art detector to meet all the ILC physics requirements with built in robustness against machine induced backgrounds. Starting with the all important calorimetry performance, particle flow calorimetry is needed with the coil located outside the calorimeter. Fine granularity is required for the particle flow calorimetry, leading naturally to the choice of the finely grained silicon tungsten electromagnetic calorimeter. Since this calorimeter is expensive, the detector architecture calls for a compact geometry. Tracking precision can be achieved in this model by a large magnetic field and high spacepoint precision silicon tracking A benefit of the large magnetic field is the tighter envelope of the beamstrahlung pairs leading to a possibility of a smaller beampipe with very close vertexing. SiD consists of cylindrical geometry (barrel and end caps), vertex detectors, silicon strips trackers, silicon tungsten electromagnetic calorimetry, and a hadronic calorimeter, all inside the 5 T solenoid, and followed by a flux return with additional muon identification Disk detectors in both the vertex detector and the tracker will be deployed to provide good tracking coverage down to 140 mrad and forward calorimeters will extend detector below 140 mrad to measure the luminosity normalization with Bhabha pairs, to measure the instantaneous luminosity with beamstrahlung pairs and gammas, and to extend the hemeticity of calorimetry. Silicon technology is integral to achieving the requirements. SiD is fast, robust against machine-induced background, fine in segmentation, and by now a mature concept. Each of the other concepts makes a different choice to achieve the physics goals.

**Table 1.** Some key parameters of the four detector concepts

| Concept | Main Tracking Technology | Solenoidal Field (Tesla) | Radius, Length of Solenoid (meters) | Rvtx (mm) | Recal Lecal (meters) | Rmax, L/2 (meters) |
|---|---|---|---|---|---|---|
| GLD | TPC | 3 | 4,9.7 | 20 | 2.1,2.8 | 7.65, 8.0 |
| LDC | TPC | 4 | 3,6.6 | 15.5 | 1.58,2.3 | 5.98,5.60 |
| SiD | Silicon | 5 | 2.5,5.5 | 14 | 1.27,1.27 | 6.45,5.89 |
| 4th | TPC | 3.5 | 3,8 | 15 | 1.5,1.8 | 5.5,5.5 |

Detector R&D is developing the technical capabilities required of ILC experiments. Several projects are active world-wide, covering most aspects needed to achieve the integrated experimental detectors of the ILC. Two examples illustrate this work: development of a very fine grained silicon-tungsten (Si-W) electromagnetic calorimeter for SiD, and of a vertex detector sensor with single bunch crossing time stamping, the Chronopixel, by an Oregon-Yale collaboration.

With high density and segmentation Si-W plays a critical role in particle flow jet energy measurements, providing, for example, separability of W and Z jets.[8] The few mm segmentation possible with a Si-W ECal provides outstanding reconstruction and isolation of individual photons with good electromagnetic energy resolution of $\sim 15\% / \sqrt{E}$ . Also excellent lepton reconstruction results from this imaging calorimeter, crucial for many new physics signatures. An outstanding technical issue is integration of silicon detectors containing about 50 million pixels with readout electronics and the associated integrated power The need for sensitivity to muon tracks and the full pulse height of electromagnetic showers leads to a dynamic range requirement of $2\times10^4$. Si-W naturally allows high transverse segmentation (3.5 mm) and a small readout gap (1 mm), maintaining a small Moliere radius. Thirty longitudinal sampling layers are planned, twenty of thickness 5/7 $X_0$ followed by ten of 10/7 $X_0$ .

The readout chip (KpiX[9]) has been designed, and fabrication and testing of the first four rounds of prototype chips completed. The power budget is limited by power pulsing and the dynamic range requirement is achieved by dynamic switching of amplifier gain ranges.

Measurements on 6-inch Hamamatsu prototypes have emphasized parameters relevant to the use of the sensors with the electronics design. The most important measurements are stray capacitance and leakage current. An absolute calibration with a radioactive source has also been investigated.

In most cases the noise of a pixel charge measurement is directly proportional to the total capacitance input to the amplifier, dominated by the stray capacitance of traces connecting pixels to the bump-bonding array. Hamamatsu detectors with oxide metal layers about 0.9 μm thick and 6 μm thick traces give a theoretical capacitance of approximately 3.1 pF/cm. The total stray capacitance of a given pixel has two comparable contributions: one from the capacitance of the traces connecting the pixel to the bump bonding array, and a second due to traces from other pixels which cross the given pixel. Another important property of the detectors is trace series resistance (Rs), with a noise contribution for a given bandwidth proportional to $C_{tot}\sqrt{Rs}$, where $C_{tot}$ is the total input capacitance. It is desirable to keep this noise term comparable to the input FET noise or Rs ~300Ω. The measured trace resistance is 57±2 Ω/cm. For the longest traces (~10cm) the measured value implies a maximum resistance of ~600 Ω. Leakage current measurements indicate the noise contribution to be minimal ~250 electrons.

Since the largest change in response is due to the electronics an internal calibration system provides an accuracy within a chip of ~1%. Chip to chip variations could be larger. Each sensor might be calibrated after the readout chip has been bump bonded with 60 keV photons from $^{241}$Am. Measurements indicate it should be possible to calibrate each pixel to 1%. Cross talk by capacitive couplings between the channels has been found to be at or below the 1% level.

A second example R&D project is the CMOS vertex sensor. During the past two years a feasible conceptual design that should meet the ILC requirements has been developed in collaboration with the Sarnoff Corporation through an R&D contract. In this design each 10 μm × μm pixel contains electronics to store the bunch number time of up to four hits above an adjustable threshold (thus "Chronopixels"). Hits are read out during the 199 msec between bunch trains. The 10 micron pixels achieve 3 to 4 micron precision without analog information.

The highest hit rates and occupancies result from the estimated 0.03 hits/mm/bunch crossing for the innermost layer for a bunch train pixel occupancy of about one percent. The time information (i.e. bunch crossing number) reduces the occupancy to $< 10^{-5}$ per pixel. An hspice simulation verifies functionality of this design.

The analog components of the circuit are estimated to consume most of the power, ~15 milliwatts/mm$^2$, which can be reduced by turning analog power off between bunch crossings. This reduces the average power consumption to about 0.5 watts per chip, or about 100 watts for the vertex detector, at the margin of an acceptable level. The associated currents will need to be dealt with.

Initial fabrication is planned with 0.18 micron process technology with somewhat larger pixels eventually moving to 45 nm process technology for ~15 micron pixels.

## THE PATH FORWARD

ILC R&D programs have been ramping up around the world to face the considerable challenges ahead. Existing programs have been evaluated, and an internationally agreed-upon prioritized R&D plan produced for critical items. The highest priority is recognized to be the SCRF accelerating gradient. Primary focus remains on the relatively mature TESLA nine-cell elliptical cavity, but research into alternative cavity shapes and materials goes on.

Investment into the critical R&D remains a priority, but a significant ramping-up of global engineering resources will now be required. The GDE is committed to a technically-driven schedule of supplying the Engineering Design Report in 2010, making start of construction possible as early as 2012 – consistent with expected early results from the LHC. An important aspect of the engineering design effort will be the refinement and control of the published cost estimate by "value engineering". The engineering design and fundamental R&D efforts will be integrated, since these two aspects of the project are not independent. The critical path and cost drivers have been clearly identified, and they define the priorities for the next three years of the Engineering Design phase. The R&D program will be fine-tuned to mitigate the remaining identified technical risks of the design. A key element of the engineering activity will be the formation of a qualified industrial base in each region for the SCRF linac technology. An equally critical focus will be on the civil construction and conventional facilities – the second primary cost driver – where an early site selection would clearly be advantageous.

The detector R&D and integrated detector design efforts must keep pace with progress on the ILC. The detector R&D program, which has already developed over many years, includes efforts in all regions, with inter-regional collaboration in some cases, and inter-regional coordination in all cases. The World Wide Study reviews the R&D within the global context. This R&D is critical to the success of the ILC experimental program. To focus this effort over the next few years, the current studies for four distinct concepts will be concentrated into two engineering design efforts, in time for submission of two detector EDRs along with the ILC EDR. The ILCSC is developing a process to assist this evolution, beginning with a call for Letters of Intent. The resulting two detectors are expected to have complementary and contrasting strengths, as well as broad international participation. The two should be defined by early 2009, and their engineering designs will then be completed over the next two or three years.

## CONCLUSION

The effort of the GDE of the last two years has led to a reference design for the ILC with a cost estimate. The physics and detector community is preparing in parallel with the GDE for the experimental program. The planning for engineering designs of the collider and detectors has begun, with the collider EDR to be completed in 2010 and the detectors soon after. Construction could start in 2012 considering technical constraints alone.

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