The Detailed Baseline Design for the SiD Detector Concept

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University of Texas at Arlington
(presented by Marcel Stanitzki)

for the SiD Detector Concept
Outline

• Introduction
  – Detector design
  – Design Study Organization
  – DBD Editors

• Areas of SiD included in DBD
  – summary for detector components

• Simulation/reconstruction, PFA, Benchmarking
  – see next talk by Tim Barklow

• SiD Costing

• Summary

• This is a short talk about a large design study – summarize main features of SiD, current status, and a word about the future.
SiD Detector overview

- **SiD Rationale**
  - *A compact, cost-constrained detector designed to make precision measurements and be sensitive to a wide range of new phenomena*

- **Design choices**
  - *Compact* design with 5 T field.
  - Robust all-silicon vertexing and tracking system with excellent momentum resolution.
  - Time-stamping for single bunch crossings.
  - Highly granular Calorimetry optimized for Particle Flow.
  - Iron flux return/muon identifier is part of the SiD self-shielding.
  - Detector is designed for rapid push-pull operation.
SiD Detailed Baseline Design

2003: SiD first appears at ALCPG. SiD is aimed at the NLC

2006: Detector Outline Document

2008/9: CLIC_SiD Starts for Multi-TeV machines

2009: SiD Letter Of Intent

2009: SiD validated

2011: CLIC Physics and Detectors Conceptual Design Report

2004: WWS starts the detector concept studies at the Victoria meeting: SiD, GLD, LDC
Beginning of the Silicon Detector Concept Study

2007: Detector Concept Report
First SiD workshop

Concept Phase

LoI Phase

DBD Phase

Marcel Stanitzki, LCWS 2012
Creating the SiD DBD

Main DBD Editors:
Phil Burrows (Oxford)
Lucie Linssen (CERN)
Mark Oreglia (UChicago)
Marcel Stanitzki (DESY)
Andy White (UTA)
• The DBD is a detailed description of a detector design concept, with examples of performance for selected ILC physics processes.

• The DBD is not at the level of a TDR
  - only limited engineering effort was available.

• It includes a large R&D effort, but this is not yet complete.

• Baseline choices have been made for all subsystems except the vertex detector; options are also included.

• We provide a full cost evaluation for the detector.
The SiD DBD Detector
The SiD DBD Detector
**The SiD DBD Detector - parameters**

<table>
<thead>
<tr>
<th>SiD BARREL</th>
<th>Technology</th>
<th>Inner radius</th>
<th>Outer radius</th>
<th>z max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertex detector</td>
<td>Silicon pixels</td>
<td>1.4</td>
<td>6.0</td>
<td>± 6.25</td>
</tr>
<tr>
<td>Tracker</td>
<td>Silicon strips</td>
<td>21.7</td>
<td>122.1</td>
<td>± 152.2</td>
</tr>
<tr>
<td>ECAL</td>
<td>Silicon pixels-W</td>
<td>126.5</td>
<td>140.9</td>
<td>± 176.5</td>
</tr>
<tr>
<td>HCAL</td>
<td>RPC-steel</td>
<td>141.7</td>
<td>249.3</td>
<td>± 301.8</td>
</tr>
<tr>
<td>Solenoid</td>
<td>5 Tesla</td>
<td>259.1</td>
<td>339.2</td>
<td>± 298.3</td>
</tr>
<tr>
<td>Flux return</td>
<td>Scintillator/steel</td>
<td>340.2</td>
<td>604.2</td>
<td>± 303.3</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>SiD ENDCAP</th>
<th>Technology</th>
<th>Inner z</th>
<th>Outer z</th>
<th>Outer radius</th>
</tr>
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<tr>
<td>Vertex detector</td>
<td>Silicon pixels</td>
<td>7.3</td>
<td>83.4</td>
<td>16.6</td>
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<tr>
<td>Tracker</td>
<td>Silicon strips</td>
<td>77.0</td>
<td>164.3</td>
<td>125.5</td>
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<tr>
<td>ECAL</td>
<td>Silicon pixel-W</td>
<td>165.7</td>
<td>180.0</td>
<td>125.0</td>
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<tr>
<td>HCAL</td>
<td>RPC-steel</td>
<td>180.5</td>
<td>302.8</td>
<td>140.2</td>
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<tr>
<td>Flux return</td>
<td>Scintillator/steel</td>
<td>303.3</td>
<td>567.3</td>
<td>604.2</td>
</tr>
<tr>
<td>LumiCal</td>
<td>Silicon-W</td>
<td>155.7</td>
<td>170.0</td>
<td>20.0</td>
</tr>
<tr>
<td>BeamCal</td>
<td>Semiconductor-W</td>
<td>277.5</td>
<td>300.7</td>
<td>13.5</td>
</tr>
</tbody>
</table>
Vertex Detector

- **Requirements**
  - < 5 µm hit resolution
  - ~ 0.1 % $X_0$ per layer
  - < 130 µW/mm²
  - Single bunch timing resolution

- ILC bunch timing and low radiation environment allows very light, low power vertex system
- Pulsed power/DC-DC conversion
- Forced dry air cooling
No preferred technology – many choices/still an evolving picture

Example 3-D/active edge design:

**Barrel**
Readout and power connections on top layer

**Disk tiling**
VIP 2a – 3 tier MIT-LL

VIP 3D chip

VIP

• VIP2a (3-tier MIT-LL chip) is produced and tested
• Both analog and digital sections work well, solving problems found in VIP1
• VIP2b (2-Tier Tezzaron/Global foundries) is in process.
• Initial tests of 2D test devices shows good analog performance.
noise = 8e + 0.5 e/ff
• Sensors for 3D integration of VIP2b produced and tested.

Chronopixel

• Measured noise of 24 e, specification is 25 e.
• Sensitivity measured to be 35.7 μV/e, exceeding design spec of 10 μV/e.
• Comparator accuracy 3 times worse then spec, need to improve this in prototype 2.
• Sensors leakage currents (1.8·10^-8 A/cm²) is not a problem.
• Readout time satisfactory
• Prototype 2 late 2011, 65nm TSMC

Next: Full sized ladder for barrel, wedge segment for disks, support structures, cooling. power pulsing, cabling.
ILC Physics requires:
- excellent momentum resolution over wide $P_T$ range
- high point precision, mechanical stability for high $P_T$
- low material budget for low $P_T$
- high efficiency for all momenta/angles

-> Performance goals

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design Goal</th>
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<tbody>
<tr>
<td>coverage</td>
<td>hermetic above $\theta \sim 10^\circ$</td>
</tr>
<tr>
<td>momentum resolution $\delta(1/p_T)$</td>
<td>$\sim 2 - 5 \times 10^{-5}/GeV/c$</td>
</tr>
<tr>
<td>material budget</td>
<td>$\sim 0.10 - 0.15X_0$ in central region</td>
</tr>
<tr>
<td></td>
<td>$\sim 0.20 - 0.25X_0$ in endcap region</td>
</tr>
<tr>
<td>hit efficiency</td>
<td>$&gt; 99%$</td>
</tr>
<tr>
<td>background tolerance</td>
<td>Full efficiency at $10 \times$ expected occupancy</td>
</tr>
</tbody>
</table>

12/14/2012  SiD DBD ILC PAC  14
Silicon Tracking

Below 20% $X_0$ for whole VTX/TRK system
Silicon Tracking

Design features:
- Single-sided silicon micro-strips, double metal layer
- KPiX readout, with time stamping
- Gas cooling
- DC-DC converters supply high instantaneous current

Realization:

Barrel silicon module
300 µm Si, 25(50) µm sense(readout) pitch

Barrel sensor with prototype pigtail cable.
Silicon Tracking

Performance - efficiency

Single muons

Di-jet $Z'$
$(M = 1$ Tev$/$c$^2)$
Silicon Tracking

Performance

Momentum resolution

Impact parameter
Tracker Alignment

SiD Alignment is based on:

1. Small number of robust, rigid elements
   - Minimize deviations
2. Precise positioning of smaller components during fabrication and assembly
   - Achieving ~ 20 μm (or better) precision
3. Real-time monitoring of alignment changes, including during push-pull moves
   - Using FSI, laser-tracks, and strain measurements using fibers
   - Building on ATLAS, CMS and AMS experiences
4. Track-based alignment for final precision
   - For each data-taking period
   - Overall accuracy ~ 3 μm (Tracker) / ~ 1 μm (Vertex)
SiD Calorimetry is designed for the PFA approach:
- ECAL and HCAL must be “imaging”: high granularity
- Small Moliere radius for ECAL – separate $e^-$/charged h
- Minimize gap between tracker and ECAL
- Sufficient overall depth

- **SiD ECAL**
  - Tungsten absorber
  - 20+10 layers
  - $20 \times 0.64 + 10 \times 1.30 \times X_0$

- **Baseline Readout using**
  - 5x5 mm$^2$ silicon pads

- **SiD HCAL**
  - Steel Absorber
  - 40 layers
  - $4.5 \lambda_i$

- **Baseline readout**
  - 1x1 cm$^2$ RPCs
All other options (except a scintillator ECAL) are being considered.
Electromagnetic Calorimetry
Electromagnetic Calorimetry

Option: Monolithic Active Pixels (MAPS)  
50µm x 50µm pixels

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>pixel size</td>
<td>13 mm²</td>
</tr>
<tr>
<td>readout gap</td>
<td>1.25 mm</td>
</tr>
<tr>
<td>effective Molière radius (incl. 0.32 mm thick Si sensors)</td>
<td>14 mm</td>
</tr>
<tr>
<td>pixels per silicon sensor channels per KPiX chip</td>
<td>1024</td>
</tr>
<tr>
<td>dynamic range requirement</td>
<td>~ 0.1 to 2500 MIPs</td>
</tr>
<tr>
<td>heat load requirement</td>
<td>20 mW per sensor</td>
</tr>
</tbody>
</table>
Hadronic Calorimetry

Steel absorber
40-layers, 4.5 $\lambda_I$
Tracking calorimeter
RPC Baseline. 1x1 cm$^2$ cells
Hadronic Calorimetry

Baseline: RPC DHCAL

- 2-glass design can operate at good efficiency and low multiplicity
- 1-glass design has flat multiplicity vs. efficiency - still being understood/under development)
Hadronic Calorimetry

Baseline: RPC DHCAL

Test beam with 1 m³ stack
Largest Calorimeter by channel count

8 GeV pion shower
120 GeV proton shower.
Hadronic Calorimetry

Baseline: RPC DHCAL

- The RPC technology is a great candidate for the readout of a highly segmented calorimeter.
- The dark rate in the DHCAL is very low
- The response is linear up to about 30 GeV/c.
Hadronic Calorimetry

Options: GEM, Micromegas, Scintillator

GEM

Micromegas

Scintillator
Muon System

- Muon identification/hadron rejection
- Flux return
- Tail catcher for calorimeter system
- Low rates/large area

Pion misidentification
10 layers
Muon System

Major change of baseline vs. LOI:
Scintillating strips/wavelength shifting fibers

(RPC remains as an option)

Development of system to position SiPM at the end of a fiber
Magnet System

- 5 T design based on 4 T CMS solenoid
- Muon system flux return

  - ANSYS 2-D and 3-D models used in design work
  - Benefitted from cryo engineering at SLAC and BNL and advances in computation
Electronics and DAQ - Rates

- SiD Electronics and DAQ built around KPiX approach → Maximize common components

<table>
<thead>
<tr>
<th></th>
<th>cell size (mm$^2$)</th>
<th>number of channels ($10^6$)</th>
<th>av. to max. occ. (%)</th>
<th>approx. # bits per hit (bit)</th>
<th>data volume (Mbyte)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VTX barrel</td>
<td>0.02 x 0.02</td>
<td>408</td>
<td>50 - 60</td>
<td>32</td>
<td>1600</td>
</tr>
<tr>
<td>VTX disks inner</td>
<td>0.02 x 0.02</td>
<td>295</td>
<td>4 - 70</td>
<td>32</td>
<td>100</td>
</tr>
<tr>
<td>VTX disks outer</td>
<td>0.05 x 0.03</td>
<td>980</td>
<td>0.5 - 20</td>
<td>32</td>
<td>40</td>
</tr>
<tr>
<td>TRACKER barrel</td>
<td>0.05 x 100</td>
<td>16</td>
<td>12 - 300</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>TRACKER disks</td>
<td>0.05 x 100</td>
<td>22</td>
<td>4 - 500</td>
<td>32</td>
<td>4</td>
</tr>
<tr>
<td>ECAL barrel</td>
<td>3.5 x 3.5</td>
<td>72</td>
<td>-</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>ECAL endcap</td>
<td>3.5 x 3.5</td>
<td>22</td>
<td>-</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>HCAL barrel</td>
<td>10 x 10</td>
<td>30</td>
<td>-</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>HCAL endcap</td>
<td>10 x 10</td>
<td>5</td>
<td>-</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>LumiCal</td>
<td>2.5 x var.</td>
<td>0.061</td>
<td>-</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>BeamCal</td>
<td>2.5(5.0) x var.</td>
<td>0.076</td>
<td>-</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>MUON barrel</td>
<td>41 x var.</td>
<td>0.026</td>
<td>-</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>MUON endcap</td>
<td>41 x var.</td>
<td>0.022</td>
<td>-</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>
Detector Integration and MDI

3 m thick concrete push-pull platform:
- 30 m travel for detector swap
- ~1 mm max static deflection at detector support points

IR Hall configuration (vertical access)
Detector Assembly - examples

Assembly beam

Assembly Spider

Insertion beam

Truck with HCAL Module

Assembling the Hadron Calorimeter

Horizontal access – moving the solenoid
Beampipe/Forward Region
Beampipe/Forward Region

LumiCal - integrated luminosity and luminosity spectrum

BeamCal – small angle coverage (with LumiCal), instantaneous luminosity

Dedicated ASIC (Bean chip) for high luminosity region
SiD Costs

- Costing is based on SiD **Parametric Model**
- Basic items have agreed cost (SiD, ILD and CLIC):

<table>
<thead>
<tr>
<th>Material</th>
<th>agreed unit cost (US-$)</th>
<th>agreed error margin (US-$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tungsten for HCAL</td>
<td>105/kg</td>
<td>45/kg</td>
</tr>
<tr>
<td>Tungsten for ECAL</td>
<td>180/kg</td>
<td>75/kg</td>
</tr>
<tr>
<td>Steel for Yoke</td>
<td>1000/t</td>
<td>300/t</td>
</tr>
<tr>
<td>Stainless Steel for HCAL</td>
<td>4500/t</td>
<td>1000/t</td>
</tr>
<tr>
<td>Silicon Detector</td>
<td>6/cm^2</td>
<td>2/cm^2</td>
</tr>
</tbody>
</table>

- Costs in 2008 U.S. $

  - M&S 315 $M
  - Contingency 127 $M
  - Labor 748 $M

- Model allows exploration of sensitivity to cost increase and detector parameter changes
Note: For the LOI an optimal cost region was found near the baseline parameters:

\[ R_{\text{tracker}} = 1.25 \text{ m}, \quad B = 5 \text{ T}, \quad \text{HCAL } \lambda_l = 4.5 \]

Cost of Tungsten HCAL has been evaluated (requested by IDAG)

No potential savings
SiD Production Status

• 3000 CPU days and 79000 Jobs
• 89 % Efficiency (Jobs successful)
SiD DBD Summary and Beyond

- We have presented a detailed design for a detector capable of high precision physics studies and discoveries at the ILC.

- Our technology choices are based on the currently available R&D results from SiD, CALICE, FCAL and other sources.

- We will continue to study/develop the SiD concept and pursue additional physics studies.

- As the ILC moves towards realization, we will expand SiD globally and work energetically with the new Linear Collider Organization to promote the ILC project

SiD研究グループは、日本でDBDを紹介する機会を与えてもらえましたことを大変光栄に思います。
This will be a critical meeting as we move forward from the DBD towards the next phase of the realization of the ILC and the SiD detector concept.
Extra slides
## SiD Elements, Masses and Sizes

<table>
<thead>
<tr>
<th>Name</th>
<th>Mass ($10^3$ kg)</th>
<th># Subcomponents</th>
<th>Mass ($10^3$ kg)</th>
<th>Size (m×m)</th>
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</thead>
<tbody>
<tr>
<td><strong>Barrel</strong></td>
<td>4220</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>ECAL</td>
<td>60</td>
<td>12</td>
<td>5.0</td>
<td>2.8 × 3.5</td>
</tr>
<tr>
<td>HCAL</td>
<td>367</td>
<td>12</td>
<td>31.7</td>
<td>5 × 5.9</td>
</tr>
<tr>
<td>Tracker</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2.5 × 3.3</td>
</tr>
<tr>
<td>Coil</td>
<td>180</td>
<td>2</td>
<td>90</td>
<td>6.8 × 5.9</td>
</tr>
<tr>
<td>Magnet Yoke</td>
<td>3360</td>
<td>8</td>
<td>420</td>
<td>12 × 5.9</td>
</tr>
<tr>
<td>Yoke Arch Supports</td>
<td>150</td>
<td>2</td>
<td>75</td>
<td>12 × 1</td>
</tr>
<tr>
<td>Peripherals</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Each of Two Endcaps</strong></td>
<td>2450</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECAL</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>0.15 × 2.5</td>
</tr>
<tr>
<td>HCAL</td>
<td>23</td>
<td>1</td>
<td>23</td>
<td>1.2 × 2.8</td>
</tr>
<tr>
<td>Muon System</td>
<td>30</td>
<td></td>
<td></td>
<td>2.6 × 12</td>
</tr>
<tr>
<td>MDI Components</td>
<td>10</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Endcap Steel Plates</td>
<td>2200</td>
<td>11</td>
<td>200</td>
<td>0.2 × 12</td>
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<tr>
<td>Endcap Leg Supports</td>
<td>140</td>
<td>2</td>
<td>70</td>
<td>2.6 × 6</td>
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<td>Infrastructure</td>
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</table>
SiD Push-Pull detector exchange

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secure ILC Beams</td>
<td>1 hr</td>
</tr>
<tr>
<td>De-energize magnets</td>
<td>3 hrs</td>
</tr>
<tr>
<td>Open Beamline Shielding</td>
<td>1 hr</td>
</tr>
<tr>
<td>Disconnect Beamlines</td>
<td>2 hrs</td>
</tr>
<tr>
<td>Checkout Detector Transport system</td>
<td>2 hrs</td>
</tr>
<tr>
<td>Transport Detector 20 m</td>
<td>2 hrs</td>
</tr>
<tr>
<td>Transport other detector on beamline</td>
<td>2 hrs</td>
</tr>
<tr>
<td>Connect beamline</td>
<td>2 hrs</td>
</tr>
<tr>
<td>Close Beamline shielding</td>
<td>1 hr</td>
</tr>
<tr>
<td>Check gross detector alignment &amp; adjust if necessary</td>
<td>2 hrs</td>
</tr>
<tr>
<td>Energize magnets</td>
<td>3 hrs</td>
</tr>
<tr>
<td>Safety Checks before beams</td>
<td>1 hr</td>
</tr>
<tr>
<td>Begin Beam Based alignment</td>
<td>10 hrs</td>
</tr>
</tbody>
</table>

1 day
Muon System

Barrel - two orthogonal planes of strips

Endcaps – modules slide between spacers/steel layers
Electronics and DAQ

SLAC development of ATCA-based systems

KPiX schematic

Versions of KPiX will be used for all subsystems except VTX and the high occupancy forward regions.