Outline

• History
• Context of the R&D effort
• SiD Architectural Motivation
• SiD Description
• Plans & Near Term Goals
History

• In the beginning, there was generic technology R&D
  • Reasonably well supported in Europe, less so in the US & Asia
    ◆ Calice (Calorimeter for the Linear Collider with Electrons)
    ◆ LCFI (Linear Collider Flavor ID) Pixel vertex detectors
    ◆ SILC (Si Tracking for the Linear Collider)
    ◆ Small efforts in the US:
      - Long Si strips @ UCSC
      - Si-W EMCal @ UO, SLAC, BNL

• The need for comprehensive simulation was recognized early - but there was even less support
  • SLAC group nucleated around N. Graf, concentrating on tools
  • US group sketched 3 detector outlines: Large (LD), Small (SD), and Precision (P). Exercises without proponents
  • Europeans formed ~collaboration and developed TESLA - a concept based on a large TPC w Si-W EMCal.
And then

- A few of us decided that the generic approach lacked desirable convergence properties, and began thinking about an integrated, high performance, cost contained detector that would become SiD.
  - Began accreting a few brave souls
  - Developed a parametric approach to sketching and costing SiD
  - Developed a set of critical questions needing answers before arriving at a Conceptual Design.

- The Linear Collider international organization began competing with the UN to organize many subgroups and panels with complicated names - including the WWS (World Wide Study) - which asked for “Design Studies” of “Detector Concepts” (ALCPG04, Victoria)
  - First SiD kick-off meeting at Victoria
Followed by

- Regional kick-off meetings at ECFA & ACFA in Fall ’04
- Set up a Design Study organization with (almost all) subsystem leadership identified.
  - Vast number of phone/video meetings
  - ½ day meeting at LCWS05
  - Significant get-together at Snowmass 05. First opportunity for interested people to spend some time together.
  - Workshop at FNAL in December 05. Planning for “Detector Outline” - a WWS & GDE request due at the Bangalore meeting in March.

- In parallel:
  - The (mainly) Europeans regrouped around Large Detector Concept (LDC) - basically TESLA
  - The Asian concept got bigger - Global Large Detector (GLD)
  - All concepts recognize the need for very good jet energy resolution - a.k.a Particle Flow Calorimetry (although some in the community debate this approach).
Detector Concepts

- Three + 1 detector concepts

SiD: Silicon Detector
- Small, 'all' silicon

LDC: Large Detector Concept
- TPC based

GLD: Global Large Detector

SiD: BR²

LDC: BR²

GLD: BR²
SiD Organization

Put SiD organization in place in Fall & Winter ’04/’05; form subgroups and start work in those: simulation, CAL/PFA, tracker layout & design starting quickly. Followed by: solenoid feasibility, vertex, benchmarking and others later.

SiD DESIGN STUDY COORDINATORS
J. Jaros, H. Weerts, H. Aihara & J. Karyotakis

EXECUTIVE COMMITTEE
H. Aihara, J. Brau, M. Breidenbach, J. Jaros, J. Karyotakis, H. Weerts & A. White

ADVISORY COMMITTEE
All names on this chart

VERTEXING
Su Dong

SILICON TRACKER
M. Demarteau
R. Partridge

24 January 2006

CALORIMETERS
R. Frey
J. Repond

24 January 2006

SOLENOID
FLUX RET
R. Smith

MUON
H. Band
H. E. Fisk

VERY FORWARD
W. Morse

SIMULATION
N. Graf

BENCHMARKING
T. Barklow

COST
M. Breidenbach

MDI
P. Burrows
T. Tauchi

R & D COORDINATOR
A. White

=SLAC People
SiD Concept Design Study Goals

- Design a comprehensive LC detector, aggressive in performance but constrained in cost.
- Optimize the integrated physics performance of its subsystems.
- Evolve the present starting point of SiD towards a more complete and optimized design.
- Interest the international HEP community in the experimental challenges of a LC.

Standard Physics requirements

- a) Two-jet mass resolution comparable to the natural widths of W and Z for an unambiguous identification of the final states. **Particle Flow Calorimetry**
- b) Excellent flavor-tagging efficiency and purity (for both b- and c-quarks, and hopefully also for s-quarks). **Pixellated Vertex Detector**
- c) Momentum resolution capable of reconstructing the recoil-mass to di-muons in Higgs-strahlung with resolution better than beam-energy spread. **Si Strips in high B**
- d) Hermeticity (both crack-less and coverage to very forward angles) to precisely determine the missing momentum. **Si-W EMCal**
- e) Timing resolution capable of tagging bunch-crossings to suppress backgrounds in calorimeter and tracker. **Fast detectors w timing electronics**
- f) Very forward calorimetry that resolves each bunch in the train for veto capability. **Rad hard pixel calorimetry**
Detector outline considerations

Architecture arguments

• **Accept** the notion that excellent energy flow calorimetry is required, use W-Si for EMCAL and the implications for the detector architecture...

  This is the **monster** assumption of SiD

• **Calorimeter (and tracker) Silicon is expensive, so limit area by limiting radius (and length)**
• **Maintain BR\(^2\)** by pushing **B (~5T)**
• **Excellent tracking resolution by using silicon strips**
• **5T field allows minimum VXV radius.**
• **Do track finding by using 5 VXV space points to determine track - tracker measures sagitta. Exploit tracking capability of EMCAL for V’s. Explore track finding with the Si strips.**
A high performance detector for the LC
Uncompromised performance
BUT Constrained & Rational cost

This is simulated SiD₀₀

24 January 2006
Progress so far...

The Critical area for further development & progress in SiD is simulation (with emphasis on PFA’s).

SiD now has a simulation of the detector “starting point”

Description can be found at:
http://confluence.slac.stanford.edu/display/ilc/sidmay05?showAttachments=true#attachments

This starting point is called: SiD 00
Vertexing = VXD

Design drivers:

- Smallest radius possible
- Clear pair background

Role:

- Seed tracks & vertexing
- Improve forward region

Work on mechanical layout of VXD

Z = 6.25 cm
Vertexing

Concept of VXDD support (started at Snowmass)

Issues considering:

- Thickness and mechanical design of endplate & support
- Sensor technology (several being pursued; common among all concepts; more in summary)
- Increase # layers by 1 in barrel & endcap
Tracker (Momenter??)

- 5-Layer silicon strip outer tracker, covering $R_{in} = 20$ cm to $R_{out} = 125$ cm, to accurately measure the momentum of charged particles

- Support
  - Double-walled CF cylinders
  - Allows full azimuthal and longitudinal coverage

- Barrels
  - Five barrels, measure Phi only
  - Eighty-fold phi segmentation
  - 10 cm z segmentation
  - Barrel lengths increase with radius

- Disks
  - Five double-disks per end
  - Measure R and Phi
  - Varying R segmentation
  - Disk radii increase with Z
Tracking I

- Cylinders tiled with 10x10cm sensors with readout chip
- Single sided ($\phi$) in barrel
- $R, \phi$ in disks
- Modules mainly silicon with minimal support (0.8% $X_0$)
- Overlap in $phi$ and $z$

Sensor/Power/readout motherboard modular
Tracking II

Obtained momentum resolution

WITH 2μM BEAM CONSTRAINT

SD AUG05: 5T, R=125cm
SD PETITE: 5T, R=100cm
LOW FIELD: 4T, R=125cm

At 90°

Excellent momentum resolution

0.5%
March '05 concept of open tracker; allow access to VXD

Snowmass update
Tracking IV; examples of work done

VXD seeded tracking efficiency for 5
qqbar @ 500GeV and 8 layer tracker as function of
angle from Thrust axis.

Use other track seeding for “missing” fraction (outside -in)

24 January 2006
Tracker only Track Finding - Zh

Preliminary T. Nelson

24 January 2006
Tracker Only Track Finding - ttbar
SiD Calorimetry

- We would like a detector which can examine new physics processes in such detail...
- Use it to obtain excellent jet energy resolution (through PFA).
Transverse segmentation $\sim$4mm
30 longitudinal samples, 20 $2/3 \times_0$, 10 $4/3 \times_0$
Energy resolution $\sim 15\%/\sqrt{E}$
Gap $\sim 1$mm, effective Moliere radius $\sim 12$ mm
EMCAL

Si/W pixel size:
• prototypes are 16 mm²
• readout chip: designed for 12 mm²

How small can we go?? 2-4 mm²?

Need a physics argument for smaller pixels.

\[ \rho \rightarrow \pi^+ \pi^0 \]
Wafer and readout chip connections

16 traces (maximum) from pixels to a typical bump pad row
Each trace 0.006 wide

6.20 +/- 0.04
5 mm
17.50 +/- 0.04

Bump Pad Array, v2.1
Debl1B
Unit: mm
Traces to bump pads, typical
8/28/03
R. Frey
KPiX SiD Readout Chip

Prototype now being tested at SLAC.

One cell. Dual range, time measuring, 13 bit, quad buffered

Prototype: 2x32 cells: full: 32x32

2 x 16 Si Strip

2x16 Calorimetry
### Hadron Calorimetry

Considering several options for HCal:

- $4\Lambda$ SS or Tungsten with any one of 3 readout technologies

<table>
<thead>
<tr>
<th></th>
<th>Scintillator</th>
<th>GEMs</th>
<th>RPCs</th>
</tr>
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<tbody>
<tr>
<td><strong>Technology</strong></td>
<td>Proven (SiPM?)</td>
<td>Relatively new</td>
<td>Relatively old</td>
</tr>
<tr>
<td><strong>Electronic readout</strong></td>
<td>Analog (multi-bit) or Semi-digital (few-bit)</td>
<td>Digital (single-bit)</td>
<td>Digital (single-bit)</td>
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<tr>
<td><strong>Thickness (total)</strong></td>
<td>~ 8 mm</td>
<td>~8 mm</td>
<td>~ 8 mm</td>
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<tr>
<td><strong>Segmentation</strong></td>
<td>3 x 3 cm²</td>
<td>1 x 1 cm²</td>
<td>1 x 1 cm²</td>
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<tr>
<td><strong>Pad multiplicity for MIPs</strong></td>
<td>Small cross talk</td>
<td>Measured at 1.27</td>
<td>Measured at 1.6</td>
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<tr>
<td><strong>Sensitivity to neutrons (low energy)</strong></td>
<td>Yes</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td><strong>Recharging time</strong></td>
<td>Fast</td>
<td>Fast?</td>
<td>Slow (20 ms/cm²)</td>
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<tr>
<td><strong>Reliability</strong></td>
<td>Proven</td>
<td>Sensitive</td>
<td>Proven (glass)</td>
</tr>
<tr>
<td><strong>Calibration</strong></td>
<td>Challenge</td>
<td>Depends on efficiency</td>
<td>Not a concern (high efficiency)</td>
</tr>
<tr>
<td><strong>Assembly</strong></td>
<td>Labor intensive</td>
<td>Relatively straightforward</td>
<td>Simple</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Not cheap (SiPM?)</td>
<td>Expensive foils</td>
<td>Cheap</td>
</tr>
</tbody>
</table>
Calorimetry II: PFA’s applied to SiD

A. Respereza

Note: $Z \rightarrow u, d, s$

Area of intense work in SiD

24 January 2006
Solenoid

Inner radius: ~ 2.5m to ~3.32m, L=5.4m; Stored energy ~ 1.2 GJ

Did feasibility study and convinced ourselves & others that this 5T solenoid can be built, based on CMS design & conductor.

- Same conductor as CMS
- CMS (4 layer) ➔ SiD (6 layer)
- CMS 5 modules 2.5 m long ➔ SiD 2 modules 2.6 m long

Stresses and forces comparable to CMS.
Muon system

SiD Muon System Strawman

- 24 10cm plates w/23 gaps. Muon ID studies done to date with 12 instrumented gaps. ~1cm spatial resolution? Start with 12 planes, more when needed (e.g. 1TeV).
- 6-8 planes of x, y, u or v upstream of Fe flux return for xyz and direction of charged particles that enter muon system.

µ Detector Technologies

Strips vs. pixels

- Glass & Bakelite RPCs -
- Scintillator and Photo-detectors
- GEMs
- Wire Chambers

Questions

- Is the muon system needed as a tail catcher?
- How many layers are needed (0-23)? Use HCAL?
- Position resolution needed?
MDI

- Substantial interaction with machine-specific Machine Detector Interface groups. (P. Burrows & T. Tauchi)
- 18 'urgent' questions issued by WWS/MDI to 3 detector concepts

- $L^*$ range under discussion by ILC: $3.5 \text{m} < L^* < 4.5 \text{m}$
  - Range is acceptable to SiD
- Beampipe radius:
  - effectively discussing $15 < r < 25 \text{ mm}$
  - if backgrounds allows: SiD prefers smallest $r$
- Bunch spacing: 150-300 ns acceptable to SiD

Need to specify tolerable background rates
Refine answers to questions MDI questions
SiD Costs

- Costs have been analyzed as a sum of:
  - ~Fixed costs tabulated in the SLAC WBS program
  - Parametric costs tied to a consistent model of SiD

- Costing done US DOE style and explicitly include:
  - M&S
  - Labor
  - Contingencies for M&S and Labor
  - Escalation
  - Indirects

- Conversion to other cost styles (e.g. ITER) seems possible by dropping subset of cost categories and then simple currency conversion. Range is $500M to $200M!
SiD Costs

SiD Costs by type

Cost Category

SiD Costs by category

Cost by subsystem

Present rough cost estimate
~5% of ILC

M. Breidenbach
Parametric Cost Plots

- **BR^2 Fixed, Vary R_Trkr**
  - Graph showing cost vs R_Trkr.
  - Range of R_Trkr from 0 to 3.
  - Cost range from 0 to 800.
  - Including cost and d$/dR values.

- **Fixed B, Vary R_Trkr**
  - Graph showing cost vs R_Trkr.
  - Range of R_Trkr from 0 to 3.
  - Cost range from 0 to 800.
  - Including cost and d$/dR values.

*Cost vs R_Trkr, BR^2 fixed, B Fixed*
SiD: salient features

- Smallest $L^*$, compatible with crossing-angle reach
- VXD: smallest radius (5T helps)
- Tracker: excellent $\delta p/p$; silicon robust; minimize material uniformly over $\cos(\theta)$; demonstrated pattern recognition (in $\rightarrow$ out; out $\rightarrow$ in, stand alone)
- ECAL: excellent segmentation 4x4 mm, $R_{\text{Moliere}}=13$ mm
- HCAL: excellent segmentation
- Calorimetry: imaging, hermetic
- Solenoid: feasible, 5T
  - Instrumented flux return & imaging HCAL: excellent muon ID
- Time stamp/digitize bunch by bunch
- Cost: constrain cost, have a parametric model
Critical Questions

- **Optimize EMCal radius, \( \cos(\theta_{\text{tracker}}) \), and \( B \) w.r.t. physics capability and detector cost.**
  
  - Requires:
    - Design of HCal, particularly
      - Detector choice (gas vs plastic)
      - Radiator choice (W vs Fe)
      - Thickness & segmentation
    - Demonstration of:
      - performance for \( K_L^0 \)'s and neutrons
      - particle separation capability
      - jet resolution
      - confidence in calorimetry algorithm optimization.

- **Tracker issues:**
  - Forward tracker performance & pattern recognition
  - Importance of \( \cos(\theta_{\text{tracker}}) \)
  - Importance of tracker thickness - jet res; lepton ID
Less but still Critical Questions

- **Tracker**
  - $N_{\text{layers}}$: all axial?
  - Double sided forward? “Pixel” size?

- **VXD**
  - What is the sensor?
  - Geometry?
  - How important is thin?

- **Muon System**
  - $N_{\text{layers}}$
  - Detector pixellization and technology

- **Forward Systems**
  - Design & strategy needed - barely can ask questions!
ILC Context

- **What crossing angle is desirable?**
  - **Oversimplified, small angles have:**
    - Better hermeticity sensitivity to SUSY
    - Slightly better “luminosity” backgrounds
    - Riskier machine backgrounds
    - Riskier downstream beamline instrumentation
    - Less need for in detector crossing angle compensation (DID)
  - And many others, but
- **All seem small compared to discussions of:**
  - Only 1 detector
  - Only 1 Interaction Region
SLAC People

- Simulation
  - N. Graf*, T. Johnson, R. Cassell, J. McCormick
- MDI & Backgrounds
  - M. Woods*, T. Maruyama, T. Markiewicz, K. Moffeit
- EMCal
  - G. Haller, D. Freytag, R. Herbst, mb
- Tracker Studies
  - T. Nelson, J. Jaros
- Physics Benchmarks
  - T. Barklow*
- VXD Studies
  - Su Dong*

* indicates intention to be in the SLAC LHC ATLAS effort
R&D needs & priorities

Concepts have been asked to identify and prioritize their R&D needs.

Draft of R&D report submitted:

**Top Down approach: R&D needs of subsystems:**

<table>
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<tr>
<th>SiD Subsystem</th>
<th>Cost</th>
<th>Estimated R&amp;D</th>
<th>R&amp;D Cost</th>
<th>R&amp;D Contingency</th>
<th>R&amp;D Cost With Contingency</th>
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<td><strong>74.7</strong></td>
<td><strong>20.0</strong></td>
<td><strong>89.7</strong></td>
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</table>

Next Step: Prioritize R&D needs of SiD; started at Snowmass
Detector Design/Development needed NOW to move ILC along

- B. Barish's ILC timeline pushes the Detector Schedule. Detector R&D Needs due late 2005; Detector Concepts and Costs due 2006; Detector CDR needed prior to Machine TDR.

- Significant R&D challenges need time: 1k channel, low power ASICs; fast VXD readout technologies; hadronic calorimetry technology; beamline instrumentation.

- US ILC R&D commitment is dangerously behind European effort. Can't (shouldn't?) afford to miss this opportunity.
Looking towards near future

• Evolve SiD₀₀ towards a more optimized baseline: explore variations of current starting point: B, R tracker, barrel length plus others and optimize using some physics benchmarks while maintaining control of costs.

• Need PFA with sufficient accuracy and sensitivity to do this.
• Progress on EMCal Si electronics – now debugging.
• Beginning hardware effort on Si strips

Future, but not so near

SLAC has a dominant role in ILC machine but rather modest in ILC detector/physics. Is this what we want?