ILC detectors:

1) the SiD concept
2) detector R&D in the US

Harry Weerts
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Outline

Two parts

The SiD detector concept for the ILC

- Physics Introduction
- Detector requirements
- SiD assumptions
- Detector description & performance
- Areas for collaboration
- Future plans

ILC detector R&D program in US

- Detector R&D in US
- Funding up to now
- Future plans & requests
The future I; will happen

The first BIG step in completing the Standard Model and looking beyond is the Large Hadron Collider (LHC) at CERN.

Ready for 1st beam ~2008.

Proton-proton collisions at 14 TeV; expect lots of new physics & discoveries

LHC is discovery machine

Find new/unexplained phenomena & particles

Will be very difficult( impossible....) to distinguish different physics models/theories

ILC
LHC potential and need for ILC

The Large Hadron Collider (LHC), will open window to “remainder” of and physics “beyond” the Standard Model. This is the energy/mass regime from ~0.5 TeV to a few TeV Starting in 2008.....

Completing the Standard Model and the symmetries underlying it plus their required breaking leads us to expect a plethora of new physics. We will need a tool to measure precisely and unambiguously their properties and couplings i.e. identify physics.

LHC will discover them or give clear indications that they exist.

This is an e⁺e⁻ machine with a centre of mass energy starting at 0.5 TeV up to several TeV Starting next decade

H. Weerts
Difference in “energy frontier” experiments (ee)

Two main kinds of machines:

1) electron - positron (e^+e^- annihilation) colliders
2) proton-(anti)proton collider (Tevatron, future LHC)

e^+e^- annihilation:
Total energy of e^+ and e^- available as $E_{\text{cms}}$ or $\sqrt{s}$
Scan over resonances

Maximum achieved for $E_{\text{cms}} = 192$ GeV

Very clean environment; precision physics
s-channel processes through spin-1 exchange: $\sigma \sim 1/s$

Cross sections relatively democratic:
- $\sigma (e^+e^- \to ZH) \sim 0.5 * \sigma (e^+e^- \to ZZ)$

Cross sections are small; for $L = 2 \times 10^{34}$ cm$^{-2}$s$^{-1}$
- $e^+e^- \to qq, WW, tt, Hx \sim 0.1$ event /train
- $e^+e^- \to e^+e^- \gamma\gamma \to e^+e^- X \sim 200$ /train

Beyond the Z, no resonances

W and Z bosons in all decay modes become main objects to reconstruct

Need to reconstruct final states

Central & Forward region important

Highly polarized $e^-$ beam: $\sim 80\%$
ILC Physics Characteristics

- Cross sections above Z-resonance are very small
- \( s \)-channel processes through spin-1 exchange
- Highly polarized \( e^- \) beam: \( \sim 80\% \)

\[
\frac{d\sigma_{\ell\ell}}{d \cos \theta} = \frac{3}{8} \sigma_{\ell\ell}^{\text{tot}} \left[ (1 - P_e A_e)(1 + \cos^2 \vartheta) + 2(A_e - P_e)A_f \cos \vartheta \right]
\]

\[
A_f = \frac{2 g_{\ell\ell} \ell \ell}{g_{\ell\ell}^2 + g_{\ell\ell}^2 A_f}
\]

\( A_b = 0.94 \quad A_c = 0.67 \quad A_f = 0.15 \)

- Hermetic detectors with uniform strengths
  - Importance of forward regions
  - b/c tagging and quark identification
  - Measurements of spin, charge, mass, ...

- Analyzing power of
  - Scan in center of mass energy
  - Various unique Asymmetries
    - Forward-backward asymmetry
    - Left-Right Asymmetry
    - Largest effects for b-quarks

Errors correspond to 20 \( \text{fb}^{-1} \)

Identify all final state objects
What should ILC detector be able to do?

Identify ALL of the constituents that we know & can be produced in ILC collisions & precisely measure their properties.
(reconstruct the complete final state)

**Elementary Particles**

- **Quarks**: $u, d, s$ jets; no ID
- **Leptons**: $e, \mu$: yes
- **Gluon**: jets, no ID
- **Force Carriers**: $c, b$ jets with ID
- **W, Z** leptonic & hadronic
- $\nu$: missing energy; no ID
- $t$: final states; jets + W’s
- $\tau$: through decays

Use this to measure/identify the NEW physics.
Benchmark measurement is the measurement of the Higgs recoil mass in the channel $e^+e^- \rightarrow ZH$
- Higgs recoil mass resolution improves until $\Delta p/p^2 \sim 5 \times 10^{-5}$
- Sensitivity to invisible Higgs decays, and purity of recoil-tagged Higgs sample, improve accordingly.

Example:
- $\sqrt{s} = 300$ GeV
- 500 fb$^{-1}$
- beam energy spread of 0.1%

Goal:
- $\delta M_{ll} < 0.1 \times \Gamma_Z$

Illustrates need for superb momentum resolution in tracker
ILC requires precise measurement for jet energy/di-jet mass

<table>
<thead>
<tr>
<th>Process</th>
<th>Vertex</th>
<th>Tracking</th>
<th>Calorimetry</th>
<th>Fwd</th>
<th>Very Fwd</th>
<th>Integration</th>
<th>Pol.</th>
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- At LEP, ALEPH got a jet energy resolution of ~60%/sqrt(E)
  - Achieved with Particle Flow Algorithm (Energy Flow, at the time) on a detector not optimized for PFA
  - Significantly worse than 60%/sqrt(E) if used current measure (rms90, for example)

- This is not good enough for ILC physics program, we need to do a lot better!
ILC goal for jet energy resolution

- ILC goal: distinguish W, Z by their di-jet invariant mass
  - Well know expression: jet energy resolution ~ 30%/sqrt(E)
  - More realistic goal (from physics requirement): flat 3-4% resolution
  - The two are about equivalent for $M_{jj} \sim 100$ GeV produced at rest
- Most promising approach: Particle Flow Algorithm (PFA) + detector optimized for PFA (a whole new approach!)

Distinguish WW from ZZ, using $M_{jj}$

$e^+e^- \rightarrow ZH \rightarrow q\bar{q}bb$ @ 350GeV, 500fb-1

$M_{bb}$ of two b-jets for different jet energy resolution.

$\Delta M_b = 42$ MeV

$\Delta M_b = 50$ MeV

$\delta E_{jet} \over \sqrt{E_{jet}} = 0.3$

$\delta E_{jet} \over \sqrt{E_{jet}} = 0.6$

$\rightarrow$ 40% luminosity gain
Some Detector Design Criteria

Requirement for ILC

- Impact parameter resolution
  \[ \sigma_{r\phi} \approx \sigma_{rz} \approx 5 \pm 10 / (psin^{3/2} \theta) \]

- Momentum resolution
  \[ \sigma \left( \frac{1}{p_T} \right) = 5 \times 10^{-5} (GeV^{-1}) \]

- Jet energy resolution goal
  \[ \frac{\sigma_E}{E} = 30\% \quad \frac{\sigma_E}{E} = 3 - 4\% \]

- Detector implications:
  - Calorimeter granularity
  - Pixel size
  - Material budget, central
  - Material budget, forward

Compared to best performance to date

- Need factor 3 better than SLD
  \[ \sigma_{r\phi} = 7.7 \pm 33 / (psin^{3/2} \theta) \]

- Need factor 10 (3) better than LEP (CMS)

- Need factor 2 better than ZEUS
  \[ \frac{\sigma_E}{E} = 60\% \]

- Detector implications:
  - Need factor ~200 better than LHC
  - Need factor ~20 smaller than LHC
  - Need factor ~10 less than LHC
  - Need factor ~ >100 less than LHC

Observation:
LHC: staggering increase in scale, but modest extrapolation of performance
ILC: modest increase in scale, but significant push in performance
To be able to achieve the jet resolution can NOT simply use calorimeters as sampling devices.

Have to use “energy/particle flow”. Technique has been used to improve jet resolution of existing calorimeters.

Algorithm:

- use EM calorimeter (EMCAL) to measure photons and electrons;
- track charged hadrons from tracker through EMCAL,
- identify energy deposition in hadron calorimeter (HCAL) with charged hadrons & replace deposition with measured momentum (very good)
- When completed only E of neutral hadrons (K’s, Lambda’s) is left in HCAL. Use HCAL as sampling cal for that.

Imaging cal (use as tracker = like bubble chamber),

⇒ very fine transverse & longitudinal segmentation

Require:

Large dynamic range: MIP.... to .....shower
Excellent EM resolution

Design Driver for any ILC detector
“Jet Energy measurement =PFA” is the starting point in the SiD design.

Premises at the basis of concept:
- Particle flow calorimetry will deliver the best possible performance.
- Si/W is the best approach for the ECAL and digital calorimetry for HCAL.
- Limit calorimeter radius to constrain the costs.
- Boost B-field to maintain BR².
- Use Si tracking system for best momentum resolution and lowest mass.
- Use pixel Vertex detector for best pattern recognition.
- Keep track of costs.

Detector is viewed as single fully integrated system, not a collection of different subdetectors.
SiD Starting Point Details & Dimensions

Flux return/ muon
- $R_{in} = 333$ cm
- $R_{out} = 645$ cm

Solenoid: 5 T; $R_{in} = 250$ cm

HCAL Fe: 34 layers; $R_{in} = 138$ cm

EMCAL Si/ W: 30 layers $R_{in} = 125$ cm

Si tracking: 5 layers; $R_{in} = 18$ cm

Vertex detector:
- 5 barrels, 4 disks; $R_{in} = 1.4$ cm
Vertexing and Tracking

- Tracking system is conceived as an integrated, optimized detector
  - **Vertex detection**
    - *Inner central and forward pixel detector*
  - Momentum measurement
    - *Outer central and forward tracking*
  - Integration with calorimeter
  - Integration with very far forward system

- Detector requirements (vertex)
  - Spacepoint resolution: < 4 \( \mu m \)
  - Impact parameter resolution
    \[ \sigma_{r\phi} \approx \sigma_{rz} \approx 5 \times 10^{-10} / (p \sin^{3/2} \theta) \, \mu m \]
  - Smallest possible inner radius
  - Momentum resolution 5 \( 10^{-5} \) (GeV\(^{-1}\))
  - Transparency: \(~0.1\% \, X_0\) per layer
  - Stand-alone tracking capability
**Vertex Detector**

- **Five Barrels**
  - $R_{in} = 14$ mm to $R_{out} = 60$ mm
  - 24-fold phi segmentation
  - two sensors covering 6.25 cm each
  - All barrel layers same length

- **Four Disks per end**
  - Inner radius increases with $z$

---

Small radius possible with large B-field

Goal is 0.1% $X_0$/layer (100 $\mu$m of Si):

- **Address electrical aspects:**
  - *Very thin, low mass sensors, including forward region*
    - Integrate front-end electronics into the sensor
  - *Reduce power dissipation so less mass is needed to extract the heat*

- **Mechanical aspects:**
  - *Integrated design*
  - *Low mass materials*
Vertex detector

A lot of effort going into mechanical/electrical design considerations for vertex detector and tracking system

Example of current thinking
**Vertex Detector Sensors: The Challenge**

**Beam structure**

![Diagram showing beam structure with time intervals and hit density]

**What readout speed is needed?**

- Inner layer 1.6 MPixel sensors; Background hits significantly in excess of 1/mm² will give patterns recognition problems
  - *Once per bunch = 300ns per frame*: too fast
  - *Once per train ~100 hits/mm²*: too slow
  - 5 hits/mm² => 50µs per frame: may be tolerable

**Fast CCDs**

- Development well underway
- Need to be fast (50 MHz)
- Read out in the gaps

**Many different developments**

- MAPS
- FAPS
- HAPS
- SOI
- 3D

For SiD: cumulative number of bunches to reach hit density of 1/mm²

- Layer 1: ~35
- Layer 2: ~250
Silicon Outer Tracker

- 5-Layer silicon strip outer tracker, covering $R_{in} = 20 \text{ cm}$ to $R_{out} = 125 \text{ cm}$, 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
Tracker Design

Baseline configuration

- Cylinders are tiled with 10x10cm² modules with minimal support
- Material budget 0.8% $X_0$/layer
- z-segmentation of 10 cm
- Active volume, $R_i=0.218$ m, $R_o=1.233$ m
- Maximum active length = 3.3 m
- Single sided in barrel; $R, \phi$ in disks
- Overlap in phi and z

- Nested support
- Power/Readout mounted on support rings
- Disks tiled with wedge detectors
- Forward tracker configuration to be optimized
Si Sensor Module/Mechanics

- Sensor Module Tiles Tracker Cylinders, Endcaps
- Kapton cables route signals and power to endcap modules
- Next steps: FEA and Prototyping
Tracking Performance

- Full simulation
- Vertex detector seeded pattern recognition (3 hit combinations)
- Event Sample
  - ttbar-events
  - $\sqrt{s} = 500$ GeV
  - background included

**Efficiency**

$\frac{\delta p_T}{p_T}$ (GeV$^2$)

Central Resolution

Black: VXD based
Red: VXD + tracker

Pt resolution $d\phi/p_{T}^2$ vs $p_T$ (GeV)
EM Calorimeter

- Particle-Flow requires high transverse and longitudinal segmentation and dense medium

- Choice: Si-W can provide $4 \times 4 \text{ mm}^2$ segmentation and minimal effective Molière radius
  - Maintain Molière radius by minimizing the gap between the W plates
  - Requires aggressive integration of electronics with mechanical design

<table>
<thead>
<tr>
<th>Absorber</th>
<th>$X_0$ [cm]</th>
<th>$R_M$ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>1.76</td>
<td>18.4</td>
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<tr>
<td>Copper</td>
<td>1.44</td>
<td>16.5</td>
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<tr>
<td>Tungsten</td>
<td>0.35</td>
<td>9.5</td>
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<tr>
<td>Lead</td>
<td>0.58</td>
<td>16.5</td>
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</table>

SLAC/Oregon/BNL Design
LAPP, Annecy, Mechanical Design

- 30 layers, 2.5 mm thick W
- ~ 1mm Si detector gaps
  - Preserve $R_M(W)_{eff} = 12 \text{ mm}$
- Pixel size $5 \times 5 \text{ mm}^2$
- Energy resolution $15\% / \sqrt{E} + 1\%$
EM Calorimeter

- **Statistics**
  - 20/10 layers, 2.5/5 mm W
  - ~ 1mm Si detector gaps
  - Tile with hexagonal 6" wafers
  - 4x4 mm² pads
  - ~ 1300 m² of Si

- **Readout with KPIX chip**
  - 1024 channels, bump-bonded
  - 4-deep buffer (low occupancy)
  - Bunch crossing time stamp for each hit
  - 32 ch. prototype in hand

\[ \rho \rightarrow \pi^+\pi^0 \]
Calorimeter Tracking

- With a fine grained calorimeter, can do tracking with the calorimeter
  - Track from outside in: $K^0_s$ and $\Lambda$ or long-lived SUSY particles, reconstruct $V$'s
  - Capture events that tracker pattern recognition doesn’t find
Hadron Calorimetry

Role of hadron calorimeter in context of PFA is to measure neutrals and allow “tracking” i.e. matching of clusters to charged particles.
- HCAL must operate with tracking and EM calorimeter as integrated system

Various Approaches
- Readout
  - Analog readout -- $O(10)$ bit resolution
  - Digital readout -- 1-bit resolution (binary)
- Technology
  - Active
    - Resistive Plate Chambers
    - Gas Electron Multipliers
    - Scintillator
  - Passive
    - Tungsten
    - Steel
- PFA Algorithms
  - Spatial separation
  - Hit density weighted
  - Gradient weighted

One simulated performance of PFA

$e^+e^- \rightarrow Z^0 \rightarrow q\bar{q}$ at 91 GeV

PFA Results
$\sigma$ (central) = 3.7 GeV
64% in central peak
**Hadron Calorimeter**

- Current baseline configuration for SiD:
  - Digital calorimeter, inside the coil
    - $R_i = 139 \text{ cm, } R_o = 237 \text{ cm}$
  - Thickness of $4\lambda$
    - 38 layers of 2.0 cm steel
    - One cm gap for active medium
  - Readout (one of choices)
    - RPC’s as active medium (ANL)
    - 1 x 1 cm$^2$ pads

All other options for HCAL are being pursued & explored.
- Gas based: RPC, GEM and micromegas (single bit / multibit)
- Scintillator based

**HCAL: area of controversy, debate, choices to be made, depth ?, simulation, related to PFA**
Event display to illustrate granularity

More detail

$\rho \rightarrow \pi^+\pi^0$
PFA performance: $e^+e^-\rightarrow qq\bar{q}(uds)$ @ 91GeV

(rms90: rms of central 90% of events)

All events, no cut
Mean 88.43 GeV
RMS 5.718 GeV
RMS90 3.600 GeV
[38.2 %/\sqrt{E}$ or $\sigma_{E_{jet}/E_{jet}}=5.8 \%$

Barrel events ($\cos(\theta[Q]) < 1/\sqrt{2}$)
Mean 89.10 GeV
RMS 4.646 GeV
RMS90 3.283 GeV
[34.7 %/\sqrt{E}$ or $\sigma_{E_{jet}/E_{jet}}=5.2 \%$

Still not quite 30%/$\sqrt{E}$ or 3-4% yet, but close now
**PFA performance: e^+e^- → ZZ @ 500GeV**

- \(Z_1 \rightarrow \text{numubar}, Z_2 \rightarrow \text{qqbar (uds)}\)
- Di-jet mass residual = (true mass of \(Z_2\) - reconstructed mass of \(Z_2\))
  - \(\mu_{90}\): mean of central 90% events
  - \(\text{rms}_{90}\): rms of central 90% events

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**SiD W/Scin HCAL**

- \(\mu_{90} = -3.5483372\)
- \(\text{RMS}_{90} = 5.35292281\)

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**SiD W/RPC HCAL**

- \(\mu_{90} = -3.08162802\)
- \(\text{RMS}_{90} = 5.41753643\)

---

**SiD SS/Scin HCAL**

- \(\mu_{90} = -2.21148477\)
- \(\text{RMS}_{90} = 5.22493307\)

---

**SiD SS/RPC HCAL**

- \(\mu_{90} = -1.68157332\)
- \(\text{RMS}_{90} = 5.43754272\)
### PFA performance: comparison

<table>
<thead>
<tr>
<th>$\text{rms}_{90}(\text{GeV})$</th>
<th>Detector model</th>
<th>Tracker outer R</th>
<th>Cal thickness</th>
<th>Shower model</th>
<th>Dijet 91GeV</th>
<th>Dijet 200GeV</th>
<th>Dijet 360GeV</th>
<th>Dijet 500GeV</th>
<th>ZZ 500GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANL(I)+SLAC</td>
<td>SiD</td>
<td>1.3m</td>
<td>~5 $\lambda$</td>
<td>LCPhys</td>
<td>3.2/9.9(^a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ANL(II)</td>
<td>LDC</td>
<td>1.7m</td>
<td>~7 $\lambda$</td>
<td>LHEP</td>
<td>2.8</td>
<td>4.3</td>
<td>7.9</td>
<td>11.9</td>
<td></td>
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<tr>
<td>Iowa</td>
<td>GLD</td>
<td>2.1m</td>
<td>5.7 $\lambda$</td>
<td>LCPhys</td>
<td>2.8</td>
<td>6.4</td>
<td>12.9</td>
<td>19.0</td>
<td></td>
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<tr>
<td>NIU</td>
<td>GLD</td>
<td>2.1m</td>
<td>5.7 $\lambda$</td>
<td>LHEP</td>
<td>2.8</td>
<td>6.4</td>
<td>12.9</td>
<td>19.0</td>
<td></td>
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<tr>
<td>PandoraPFA*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLD PFA*</td>
<td>GLD</td>
<td>2.1m</td>
<td>5.7 $\lambda$</td>
<td>LCPhys</td>
<td>2.8</td>
<td>6.4</td>
<td>12.9</td>
<td>19.0</td>
<td></td>
</tr>
<tr>
<td>30%/sqrt(E)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.86</td>
<td>4.24</td>
<td>5.69</td>
<td>6.71</td>
<td>(?)</td>
</tr>
<tr>
<td>3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.93</td>
<td>4.24</td>
<td>7.64</td>
<td>10.61</td>
<td>(?)</td>
</tr>
<tr>
<td>4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.57</td>
<td>5.67</td>
<td>10.18</td>
<td>14.14</td>
<td>(?)</td>
</tr>
</tbody>
</table>

\* From talks given by Mark Thomson and Tamaki Yoshioka at LCWS'07

- **a)** 2 Gaussian fit, (central Gaussian width/2\(^\text{nd}\) Gaussian width)
- **b)** $Z_1 \rightarrow \text{nunubar}, Z_2 \rightarrow \text{qqbar (uds)}$
- **c)** Di-jet mass residual [= true mass of Z2 - reconstructed mass of Z2]

- A fair comparison between all PFA efforts is NOT possible at the moment
- PandoraPFA (M. Thomson) achieved ILC goal in some parameter space
- SiD efforts: 30%/sqrt(E) or 3-4% goal has not been achieved yet, but we made a lot of progress during the last few years and we are much closer now
**Solenoid**

- Design calls for a solenoid with $B(0,0) = 5T$ (not done previously)
  - Clear Bore $\varnothing \approx 5 \text{ m}; L = 5.4 \text{ m};$ Stored Energy $\approx 1.2 \text{ GJ}$
    - *For comparison, CMS: 4 T, $\varnothing = 6\text{ m}, L = 13\text{ m}; 2.7 \text{ GJ}*

- Full feasibility study of design based on CMS conductor
  - Start with CMS conductor design, but increase winding layers from 4 to 6
    - $I_{CMS} = 19500 \text{ A}, I_{(SiD)} = 18000 \text{ A};$ Peak Field (CMS) 4.6 T, (SiD) 5.8
    - Net performance increase needed from conductor is modest

*Studies on Dipole in Detector (DID) have been done/are being done as well*

---

H.Weerts

KEK, 18 July, 2007
Field simulation

- ANSYS modeling of solenoid (2d, 3d)

- 23 Layers Barrel Steel

- 23 Layers End Steel

- $R = 3428$ mm
- $R_{out} = 3098$ mm
- $R_{in} = 2645$ mm

- $B(0,0) = 5.0$ T

- $B_{peak} = 5.75$ T

- $Z = 0$
- $Z = 2847$ mm
- $Z = 6247$ mm

Outer Portions of Steel Cistted from Figure

H. Weerts

KEK, 18 July, 2007
Muon System

- **Muon System Baseline Configuration**
  - Octagon: 48 layers, 5 cm thick steel absorber plates
  - Six-Eight planes of x, y or u, v upstream of Fe flux return for xyz and direction of charged particles that enter muon system.

- **Muon ID studies**
  - 12 RPC-instrumented gaps
  - ~1cm spatial resolution

- **Issues**
  - Technology: RPC, Scin/SiPMs, GEMS, Wire chambers
  - Is the muon system needed as a tail catcher?
  - How many layers are needed (0-23)? Use HCAL?
  - Position resolution needed?

---

**Eff. & Purity vs. Interaction Lengths**

- **Efficiency/Purity**
  - **Eff**
  - **Purity**

- **End of HCal**

---

KEK, 18 July, 2007
Forward Detectors & Machine Detector Interface

( includes forward calorimetry)

Machine-Detector Interface at the ILC

- (L,E,P) measurements: Luminosity, Energy, Polarization
- Forward Region Detector layout ( lumcal, beamcal, gamcal)
- Collimation and Backgrounds
- IR Design and Detector Assembly
- EMI (electro-magnetic interference) in IR
Summary: Technical Strengths

- **Generally:** compact, highly integrated, hermetic detector
  Bunch by bunch timing resolution

- **Tracking:**
  - VTD: small radius (5T helps)
  - Tracker: excellent dp/p; minimized material all \( \cos(\theta) \)
  - Demonstrated pattern recognition
  - Solenoid: 5T (difficult but not unprecedented)

- **Calorimetry:** imaging, hermetic
  - ECAL: excellent segmentation=4x4 mm\(^2\), \( R_{Moliere} = 13\) mm
  - HCAL: excellent segmentation: \(~1x1\) to 3x3 cm\(^2\)
  - Working on PFA performance

- **Excellent \( \mu \) ID:** Instrumented flux return & imaging HCAL

- **Simulation:** Excellent simulation and reconstruction software
  - Results shown only possible with that
Opportunities (incomplete list)

- Tracking
  - VTD technology
  - Optimize Si tracking (layers)
  - Forward System

- Calorimetry
  - Choice of HCAL technology requires study, PFA evaluation.
  - Overall Optimization:
    - Inner Radius
    - Depth and Length?
    - B field?
  - Forward systems challenging

- Muon
  - Technology?
  - # Layers? (Boost HCAL)

- Simulation & algorithmic tools
  - Little mention here
  - BUT there has been tremendous effort and many tools are in place)
    - Detector studies and MC benchmarking should be pursued!
    - Overall integration studies needed

Concepts under Development for International Linear Collider
- Charge-Coupled Devices (CCDs)
  - demonstrated in large system at SLD, but slow
- Monolithic Active Pixels – CMOS (MAPs)
- DEpleted P-channel Field Effect Transistor (DEPFET)
- Silicon on Insulator (SOI)
- Image Sensor with In-Situ Storage (ISIS)
- HAPS (Hybrid Pixel Sensors)
- Macro/Micro Pixel Arrays
Vertex Detector Projects

- Pixel sensor development and testing
- Mechanical design and testing
- Power delivery and signal transmission
- Vertex and flavor tagging algorithms
- Test beam program

Recently UK groups joined.

Vertex Contacts:
Su Dong
sudong@slac.stanford.edu
Ron Lipton
lipton@fnal.gov
Bill Cooper (mechanics)
cooper@fnal.gov
Tracker Projects

- Module design and testing
- Mechanical design and testing
- Alignment and vibration measurement
- Forward tracker design
- Tracking algorithms and optimization
- Test beam program

Tracker Contacts:
Marcel Demarteau
demarteau@fnal.gov
Rich Partridge
partridge@hep.brown.edu
Bill Cooper (mechanics)
cooper@fnal.gov
Calorimeter Projects

- ECal design and testing
- HCal design and testing
- Mechanical Design
- PFA development and studies
- Other Simulation studies: $\tau$, $\pi^0$, $\#\lambda$, etc.
- Test beam program

Calorimeter Contacts:
- Andy White (overall)
  awhite@uta.edu
- Ray Frey (ECal)
  rayfrey@cosmic.uoregon.edu
- David Strom (ECal)
  strom@physics.uoregon.edu
- Vishnu Zutshi (HCal)
  zutshi@nicadd.niu.edu
- Harry Weerts (HCal)
  weerts@anl.gov
- Norman Graf (PFA)
  ngraf@slac.stanford.edu
- Steve Magill (PFA)
  srm@anl.gov
Muon and Solenoid Projects

- Muon system design
- Muon tracking algorithms and studies
- Punch-through, background studies
- Test beam program
- Solenoid design

Muon/Solenoid Contacts:
Henry Band (muon)
hrb@slac.stanford.edu
Gene Fisk (muon)
hefisk@fnal.gov
Paul Karchin (muon)
karchin@physics.wayne.edu
Kurt Krempetz (solenoid)
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Forward Detector and MDI Projects

- LumCal, BeamCal, GamCal design
- MDI design
- Energy, polarimeter design
- Beam pipe design

Forward Det. Contacts:
Bill Morse (Forward)
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Phil Burrows (MDI)
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Tom Markiewicz (MDI)
twmark@slac.stanford.edu
Tauchi Toshiaki (MDI)
toshiaki.tauchi@kek.jp
Benchmarking Projects

Physics performance studies

\[ e^+ e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 W^+ W^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 q\bar{q}q \bar{q} \]
Simulation Projects

- Detailed detector simulation
- Algorithm development and detector optimization through simulation

Simulation Contact:
Norman Graf
ngraf@slac.stanford.edu
Summary

- It is a great time to get involved in SiD
- Many interesting projects that need your help
- More information can be found in the SiD talks at conferences & workshops
- Getting started is easy:

1. Identify an area in SiD where you would like to contribute
2. Talk with SiD leadership about your interests and our needs
3. Start attending meetings and begin contributing to SiD

See the SiD web page for links to further information:

http://www-sid.slac.stanford.edu
Closing Comments & The Way Forward

- A silicon-centric design offering
  - excellent tracking precision
  - new potential in calorimetry
  - good muon identification
- Complementary to other concepts
- Many opportunities for new effort and expertise.
- Tools and organization in place to support efficient development and to get started.
- Great opportunity to explore ILC detector/physics.
- Open to new ideas, collaborators, increased internationalization

Tools all in place for a workshop on optimization and choices, new ideas welcome – Fall ‘07.
“Final” choices – Spring ’08
Letter of Intent – Summer ’08
THE END
Backup slides
The World Wide Study Organizing Committee has established the Detector R&D Panel to promote and coordinate detector R&D for the ILC. Worldwide activities at:
- https://wiki.lepp.cornell.edu/wws/bin/view/Projects/WebHome

ILC detector R&D needs: funded & needed

Urgent R&D support levels over the next 3-5 years, by subdetector type. 'Established' levels are what people think they will get under current conditions, and 'total required' are what they need to establish proof-of-principle for their project.
Backgrounds

“At the ILC the initial state is well defined, compared to LHC, but....”

- Backgrounds from the IP
  - Disrupted beams
    - Extraction line losses
  - Beamstrahlung photons
  - $e^+e^-$ - pairs

- Backgrounds from the machine
  - Muon production at collimators
  - Synchrotron radiation
  - Neutrons from dumps, extraction lines

<table>
<thead>
<tr>
<th>$\sqrt{s}$ (GeV)</th>
<th>Beam</th>
<th># $e^+e^-$ per BX</th>
<th>Total Energy (TeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>Nominal</td>
<td>98 K</td>
<td>197</td>
</tr>
<tr>
<td>1000</td>
<td>Nominal</td>
<td>174 K</td>
<td>1042</td>
</tr>
</tbody>
</table>
Detector Challenges of the ILC

- Variation of the centre of mass energy, due to very high current, collimated beams: three main sources
  - Accelerator energy spread
    - Typically ~0.1%
  - Beamstrahlung
    - 0.7% at 350 GeV
    - 1.7% at 800 GeV
  - Initial state radiation (ISR)
    - Calculable to high precision in QED
    - Complicates measurement of Beamstrahlung and accelerator energy spread
    - Impossible to completely factorize ISR from FSR in Bhabha scattering

- But, there are many more challenges

Need: Reconstruct complete final state.
EM Calorimeter Layout

- Tile W with hexagonal 6” wafers
  - ~ 1300 m² of Si
  - 5x5 mm² pads
  - Readout by single chip
  - 1024 channels, bump-bonded

- Signals
  - Single MIP with S/N > 7
  - Dynamic range of 2500 MIPs
  - < 2000 e⁻ noise

- Power
  - < 40 mW/wafer through power pulsing!
  - Passive edge cooling

- Readout with kPix chip
  - 4-deep buffer (low occupancy)
  - Bunch crossing time stamp for each hit

- Testing
  - Prototype chip in hand with 2x32 channels
  - Prototype sensors in hand
  - Test beam foreseen in 2006
These detector concepts studied worldwide, with regional concentrations

Recently submitted “Detector Outline Documents” (~150 pages each)

Physics goals and approach all similar. Approach of “4” different

SiD: Silicon Detector
- Small, ‘all’ silicon
- LDC: Large Detector Concept
  - TPC based
- GLD: Global Large Detector
  - SiD: B R²
  - LDC: B R²
  - GLD: B R²

Different: no PFA; solenoid arrangement
Calorimetry

- **Goal is jet energy resolution of 30%/√E**
- **Current paradigm is that this can be achieved with Particle Energy Flow**
- **A particle flow algorithm is a recipe to improve the jet energy resolution by minimizing the contribution from the hadronic energy resolution by reducing the function of a hadron calorimeter to the measurement of neutrons and K⁰'s only**

<table>
<thead>
<tr>
<th>Particles in jets</th>
<th>Fraction of energy</th>
<th>Measured with</th>
<th>Resolution [σ²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charged</td>
<td>~ 65 %</td>
<td>Tracker</td>
<td>Negligible</td>
</tr>
<tr>
<td>Photons</td>
<td>~ 25 %</td>
<td>ECAL with 15%/√E</td>
<td>0.07² E_jet</td>
</tr>
<tr>
<td>Neutral Hadrons</td>
<td>~ 10 %</td>
<td>ECAL + HCAL</td>
<td>0.16² E_jet</td>
</tr>
</tbody>
</table>
Why ILC detector R&D?

From a naïve perspective looks like simple problem

Extrapolating from LHC

<table>
<thead>
<tr>
<th></th>
<th>LHC</th>
<th>ILC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch Crossing</td>
<td>25 ns (40 MHz); DC</td>
<td>337 ns 0.5% duty cycle</td>
</tr>
<tr>
<td>Triggering:</td>
<td>40 MHz → 1 kHz → 100 Hz</td>
<td>No hardware trigger</td>
</tr>
<tr>
<td>L1, L2, and L3</td>
<td></td>
<td>~ 100 Hz Software</td>
</tr>
<tr>
<td>Radiation</td>
<td>1-100 MRad/yr</td>
<td>≤ 10 kRad/yr</td>
</tr>
<tr>
<td>Physics Occupancy</td>
<td>23 min. bias; 100 tracks</td>
<td>0.3 $\gamma\gamma \rightarrow$ hadrons; 2 tracks</td>
</tr>
</tbody>
</table>

But there are other factors which require better performance.....