JLC Detector Overview

Snowmass 2001
T. Tauchi (KEK), July, 2001

Contents

0. Requirements
1. JLC detector: "2T Model" and "3T Model"
2. VTX (CCD)
3. CDC
4. CAL: electromagnetic and hadronic ones
5. IR
(1) Lepton pair recoil or missing mass resolution for \( e^+e^- \rightarrow Z h \), (\( Z \rightarrow \mu^+\mu^- \) or \( e^+e^- \)) should be comparable with the beam energy spread (\( \pm 0.2\% \)).
⇒ Confirmation of narrow decay width of Higgs

**Tracking** : Good momentum resolution

(2) 2-jet invariant mass resolution should be comparable with the natural width of W and Z.

**Calorimetry** : Good energy resolution & \( e/\pi = 1 \)

- Good position resolution (\( \sigma_{em} \sim 1\text{mm} \))

**Tracking** : Good longitudinal position resolution (\( \sigma_z \sim 1\text{mm} \)) & good 2-track separation (2mm)

(3) Hermetic Calorimetry

- \(|\cos \theta| < 0.98\) for good measurement
- \(\theta_{veto} > 50\text{ mrad}\) for SUSY-particles

(4) Reconstruction of b and c-quarks

**Tracking** : secondary and tertiary decay vertexing with huge beam-background \( O(1) \text{hit/mm}^2 \)
JLC detector
"2 T model"

Calorimeter
\[ \frac{\sigma_E}{\sqrt{E}} = 15\% / \sqrt{E} \pm 1\% \text{ (e,} \gamma \text{)} \]
\[ \frac{\sigma_E}{\sqrt{E}} = 40\% / \sqrt{E} \pm 2\% \text{ (had)} \]

Central Drift Chamber
\[ \sigma_{p_t}/p_t = 1.1 \times 10^{-4} p_t \pm 0.1\% \]

Super con. magnet coil
(2 Tesla)

Muon Chamber
16x16x16 m^3
15,000 ton

Magnifying IP,

Vertex Detector
\[ \delta^2 = 11.4^2 + (28.8/P)^2 / \sin^3 \theta \]
(\mu m^2)
<table>
<thead>
<tr>
<th>detector</th>
<th>&quot;2T Model&quot;</th>
<th>JLC</th>
<th>&quot;3T Model&quot;</th>
<th>TESLA</th>
<th>NLC-S</th>
<th>- L</th>
</tr>
</thead>
<tbody>
<tr>
<td>magnet</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>6</td>
<td>X 3</td>
<td></td>
</tr>
<tr>
<td>size (m)</td>
<td>9 φ x 10 z</td>
<td>8 φ x 7.1 z</td>
<td>6.5 φ x 9.2 z</td>
<td>2.3 φ x 3.1 z</td>
<td>8.2 φ x 9.4 z</td>
<td></td>
</tr>
<tr>
<td>central tracker (CT)</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>type</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CT only</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>drift chamber</td>
<td>0.5 • 10^{-4} P_t ⊕ 0.1%</td>
<td>0.9 • 10^{-4} P_t ⊕ 0.1%</td>
<td>0.5 • 10^{-4} P_t</td>
<td>1.6 • 10^{-4} P_t</td>
<td>0.5 • 10^{-4} P_t</td>
<td></td>
</tr>
<tr>
<td>drift chamber</td>
<td>1.1 • 10^{-4} P_t</td>
<td>3 • 10^{-4} P_t</td>
<td>2 • 10^{-4} P_t</td>
<td>TPC</td>
<td>Si strips</td>
<td></td>
</tr>
<tr>
<td>n, σ (m)</td>
<td>80, 85.</td>
<td>50, 85.</td>
<td>118, 160.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>size (m)</td>
<td>0.45 &lt; r &lt; 2.3</td>
<td>0.45 &lt; r &lt; 1.55</td>
<td>0.36 &lt; r &lt; 1.6</td>
<td>0.1 &lt; r &lt; 0.75</td>
<td>0.5 &lt; r &lt; 2.0</td>
<td></td>
</tr>
<tr>
<td>calorimeter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>electromagnetic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>segmentation</td>
<td>15/ √E ⊕ 1</td>
<td>15/ √E ⊕ 1</td>
<td>10/ √E ⊕ 1</td>
<td>12/ √E ⊕ 1</td>
<td>15/ √E ⊕ 1</td>
<td></td>
</tr>
<tr>
<td>type</td>
<td>tile: Pb</td>
<td>tile: Pb(1:4 mm^3)</td>
<td>shashlik or W/Si</td>
<td>Pb W/Si</td>
<td>Pb</td>
<td></td>
</tr>
<tr>
<td>size (m)</td>
<td>1.6 &lt; r &lt; 1.86</td>
<td>1.7 &lt; r &lt; 1.9</td>
<td>0.75 &lt; r &lt; 1.1</td>
<td>2.0 &lt; r &lt; 2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ(cm)xφ(cm)</td>
<td>6 x 6</td>
<td>4 x 4</td>
<td>3 x 3 or 1 x 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hadronic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>segmentation</td>
<td>40/ √E ⊕ 2</td>
<td>40/ √E ⊕ 2</td>
<td>50/ √E ⊕ 4</td>
<td>50/ √E ⊕ 2</td>
<td>40/ √E ⊕ 2</td>
<td></td>
</tr>
<tr>
<td>type</td>
<td>tile: Pb</td>
<td>tile: Pb(2:8 mm^3)</td>
<td>tile or digital</td>
<td>Cu</td>
<td>Pb</td>
<td></td>
</tr>
<tr>
<td>size (m)</td>
<td>1.86 &lt; r &lt; 3.4</td>
<td>1.9 &lt; r &lt; 2.95</td>
<td>1.4 &lt; r &lt; 2.5</td>
<td>2.5 &lt; r &lt; 3.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>θ(cm)xφ(cm)</td>
<td>18 x 18</td>
<td>12 x 12</td>
<td>5 x 5 or 1 x 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vertex detector (VTX)</td>
<td>7.2 ⊕ 22.5 P sin^3/2 θ</td>
<td>3.0 ⊕ 24 P sin^3/2 θ</td>
<td>5 ⊕ 10 P sin^3/2 θ</td>
<td>4.5 ⊕ 5.5 P sin^3/2 θ</td>
<td>10 ⊕ 30 P sin^3/2 θ</td>
<td></td>
</tr>
<tr>
<td>type</td>
<td>CCD</td>
<td>CCD</td>
<td>CCD, CMOS,APS</td>
<td>CCD</td>
<td>CCD</td>
<td></td>
</tr>
<tr>
<td>size (cm)</td>
<td>2.4 &lt; r &lt; 6.0</td>
<td>2.4 &lt; r &lt; 6.0</td>
<td>1.5 &lt; r &lt; 10.</td>
<td>1.2 &lt; r &lt; 6.</td>
<td>1.2 &lt; r &lt; 6.</td>
<td></td>
</tr>
<tr>
<td>θ(cm)xφ(cm)</td>
<td>2.4 &lt; r &lt; 6.0</td>
<td>2.4 &lt; r &lt; 6.0</td>
<td>1.5 &lt; r &lt; 10.</td>
<td>1.2 &lt; r &lt; 6.</td>
<td>1.2 &lt; r &lt; 6.</td>
<td></td>
</tr>
<tr>
<td>type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Deformation of the outermost layer of the yoke due to its self-weight of 1,352 tons.

Defomation of the end-yoke due to magnetic force of 18,000 tons at B=3 Tesla.
# Detector R and D Status

## VTX Room temperature operation (0 – 20°C)

<table>
<thead>
<tr>
<th>R&amp;D items</th>
<th>Status and future R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Resolution</td>
<td>[ \sigma = 3.5 \mu m \text{ at } 5^\circ C (24 \times 24 \mu m^2) \text{ by RLM/10bit, } S/N &gt; 10 ]</td>
</tr>
<tr>
<td>Thinner structure</td>
<td>Mechanical design studies; Flatness at various temperatures.</td>
</tr>
<tr>
<td>Radiation Hardness</td>
<td>Dark current controlled by MPP (Multi Pinned Phase) – CCD ( V(H) - \text{CTI} )</td>
</tr>
<tr>
<td></td>
<td>The model is established. The best CCD is a 2-phase MPP mode CCD with notch, injecting &quot;fat zero&quot; &gt; 1000e charge. &gt; 10Mpixels/sec ( V(H) - \text{CTI}, 8 \times 10^{-4} ) after 10 years (5x10^{-12}e/cm2 Sr90, 5x10^{-9}n/cm2 Cf252). So, 25% charge may be lost for 250(V) x 1000(H) pixels (5 x 25 mm2).</td>
</tr>
<tr>
<td>Speed</td>
<td>0.25MHz at present, 2MHz high-speed CCD is available.</td>
</tr>
<tr>
<td></td>
<td>Need &gt;27MHz (=250,000/0.0067sec) at JLC.</td>
</tr>
<tr>
<td>Hot pixels</td>
<td>40% of them have RTS causing isolated pixel events (IPE).</td>
</tr>
<tr>
<td>Random Telegraph Signals (RTS)</td>
<td>Fast readout or cool down. IPE rate / CCD readout frame can be low at ( 10^{-4} ) with fast readout. The RTS issue can be solved by more radiation-hard devices.</td>
</tr>
</tbody>
</table>
Vertex Detector of CCD: YAG laser prober system for a measurement of spatial resolution at Niigata Univ.: Laser beam pulses of $2\times2\mu m^2$ spot size and 1064 nm wavelength are injected into CCD sensors to simulate the minimum ionizing particles. The incident position is controlled with a precision of 1µm.
Schematic design of the CCD vertex detector for JLC
+12V

Clock Pulse(+4~ -8V)

+12V

n+

n: ~1 µm

Depletion region: few µm

Potential minimum

SiO₂: 0.1 µm

n: ~1 µm

p (epitaxial): ~20 µm

p⁺ (substrate; ground): ~300 µm
Resolution (RLM) at -15 °

Residual Resolution (um)

### Infinit mom. Intrinsic Resolution

- 4.6um: 2.94±0.10um
- 4.4um: 2.76±0.03um
- 4.5um: 2.79±0.09um
Injection of additional charge (fat zero effect)

Method for charge injection in the vertical register

- Uses the characteristics of MPP operation

Pros:
- Dark charge is generated thermally
- Works on any type of MPP CCD
- No need for a special device

Cons:
- Requires precise adjustment
- Operation depends on the irradiation level
- Works only at high temperatures
Comparison between 2- and 3- phase CCD

In 2-phase CCD signal density is higher \( \Rightarrow \) LOWER CTI

- CTI model for 3-phase CCD has been developed
- Vertical CTI is dominant in both CCDs
- VCTI of 3-phase CCD is \( \approx 2.5 \) times higher than in 2-phase CCD.
Experimental comparison between 2- and 3-phase CCD:

- Hamamatsu S5466 (2-phase)
- EEV 02-06 (3-phase)

The 2-phase CCD has $\approx 4$ times lower VCTI (*)

(*) Integration time for S5466 3s, for EEV 2s; DCP in S5466.
Notch CCD

- Additional implant in the channel;
- ‘Notch’ in the potential profile;
- Small signal packets are transported in the notch;

\[ \text{CTI} = \frac{n_t}{n_s}, \]

- \( n_t \) - concentration of defects,
- \( n_s \) - concentration of signal electrons.

Signal density for small charge packets increases

Lower CTI
Hamamatsu Photonics Notch CCD has 3 μm wide additional implant in the channel.

Electron irradiation:
- Vertical (parallel) CTI is about 3 times lower than that in a conventional CCD.

Neutron irradiation:
- Vertical CTI of CCD, irradiated to $5.7 \times 10^9$ neutrons/cm$^2$ is less than $5 \times 10^{-5}$. 
Model CCD

Based on the present knowledge on radiation damage effects and device architecture

Reduced worst-case CTI:
Vertical CTI to $\approx 8 \times 10^{-4}$, output charge after 250 transfers: $(1 - 8 \times 10^{-4})^{250} = 0.82$ (18% loss)

Horizontal CTI to $\approx 8 \times 10^{-5}$, output charge after 1000 transfers: $(1 - 8 \times 10^{-5})^{1000} = 0.92$ (8% loss)

Total charge at the output: $0.82 \times 0.92 = 0.75$ (25% loss)

The CCD will survive for 10 years ($\approx 5 \times 10^{12}$ electrons/cm$^2$ $^{90}$Sr, $\approx 5 \times 10^9$ neutrons/cm$^2$ $^{252}$Cf), or for 3 years (at $15 \times 10^{12}$ electrons/cm$^2$)

Konstantin Stefanov, Saga University, Japan
# Detector R and D Status

**CDC**Jet-type drift chamber with very long wires (L=4.6m) at B=2–3T.

<table>
<thead>
<tr>
<th>R&amp;D items</th>
<th>Status and future R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gravitational and electrostatic wire sags</strong></td>
<td>30(125) µm φ sense(field) wire of goldplated tungsten (aluminum). Drift lenth&lt; 5cm in CO2/isobutane(90/10%). Gravitational sag: measured 353(600) µm v.s. calculated 312(533) µm. Asymmetry &lt;80 µm due to electrostatic sag (GARFIELD), NIM A383(96)391.</td>
</tr>
<tr>
<td><strong>Al wire tension drop</strong></td>
<td>wire tension measurement continues.</td>
</tr>
<tr>
<td><strong>Spatial resolution</strong></td>
<td>cosmic ray test and baby chamber results 85 µm, NIM A441(00)393.</td>
</tr>
<tr>
<td><strong>Stereo wires</strong></td>
<td>$\sigma_z = \sigma /\tan \alpha \sim 1$ mm, $\tan \alpha \sim 0.1$, gain variation,NIM A428(99)403</td>
</tr>
<tr>
<td><strong>Lorentz angle</strong></td>
<td>measured up to B=1.5T, agrees with GARFIELD. B=2T is OK while the extrapolation to B=3T is too ambitious !, needs more measurements. KEK Preprint 2000–113</td>
</tr>
<tr>
<td><strong>Gas gain saturation</strong></td>
<td>Quick saturation was observed by 55Fe X rays. NIM A447(00)459.</td>
</tr>
<tr>
<td><strong>dE/dX resolution</strong></td>
<td>$\sigma = 6.7(5.7)$% for 1GeV pions(protons) with a 70% truncated mean among 80 wires . It is expected that 20% worse for 50 wires at B=3T.</td>
</tr>
<tr>
<td><strong>2 track separation</strong></td>
<td>to be measured</td>
</tr>
<tr>
<td><strong>neutron background</strong></td>
<td>pure CO2 or CO2(90)/Ar(10) to be studied.</td>
</tr>
</tbody>
</table>
Figure 11.34: A possible super-layer layout for the central tracking system of the JLC.

A/UV=6/10 super layers
("2T model")

Figure 11.35: A typical geometry of a single cell: the circles (○) and (●) correspond to sense and potential wires, respectively.
4.6m CDC test chamber
for wire sag measurement
Central Drift Chamber: The so called "baby" chamber for beam-testing the performance of the mini-jet-cell of the current JLC central drift chamber design. The cell consists of 5 sense wires with a maximum drift length of 5cm and has been proved to provide an average spatial resolution better than 100 μm and 2-hit separation better than 2mm. The chamber is called a "baby", since it was built after a 4.6m long test chamber with the same cell structure; the 4.6m chamber was too big for beam tests.
resolution (wire3)

drift length (mm) vs. spatial resolution (micro meter)

electron beam (baby chamber)
cosmic-ray (4.6m chamber)
Laser Beam

Anode Wire

Cathode Pads

Lorentz angle measurement

Slit to Separate Amplification Region from Drift Region
\[ \tan \alpha = 0.159 \pm 0.002 \]
Electron drift lines from a wire

Cell: CDC cell for JLC
Gas: CO₂
Isochrone interval: 1 [μsec]
Figure 11.51: (a) FADC signals as a function of time (500 ns/division) for a typical 2-track event. (b) 2-hit separation efficiency as a function of 2-track distance.
π – p Separation by $dE/dx$ Measurement

Pion - Proton separation obtained by $dE/dx$ measurement. The energy loss is calculated by the truncated mean method using the lowest 70% of 80 measurements, each for 1-cm sampling length.
QuickSim vs JIM comparison: Momentum resolution

"3 T Model"

QuickSim vs JIM comparison: Impact parameter resolution

"3T Model"
Missing mass resolution and initial beam energy spread

$\sqrt{s}=250\text{GeV}, \text{ISR, 100fb}^{-1}$

Chi2 / ndf = 41.36 / 53
Normalization = 1.31$\pm$0.1437
Higgs mass = 120$\pm$0.001211
Gauss Width = 0.7061$\pm$0.00424

$\sigma_{\text{MM}}=0.70\text{GeV}$

$\sqrt{s}=250\text{GeV}, \text{ISR+BS+}\Delta E_B(\pm 0.5\%), \text{100fb}^{-1}$

Chi2 / ndf = 45.21 / 52
Normalization = 1.819$\pm$0.1605
Higgs mass = 120$\pm$0.01021
Gauss Width = 1.486$\pm$0.114

$\sigma_{\text{MM}}=1.01\text{GeV}$

JIM LCWS2000 A.Miyamoto

$\sqrt{s}=250\text{GeV}, \text{ISR+BS+}\Delta E_B(\pm 0.1\%), \text{100fb}^{-1}$

Chi2 / ndf = 42.3 / 53
Normalization = 1.911$\pm$0.1847
Higgs mass = 120$\pm$0.01139
Gauss Width = 1.009$\pm$0.0861

$\sigma_{\text{MM}}=0.75\text{GeV}$

$\sqrt{s}=250\text{GeV}, \text{ISR+BS+}\Delta E_B(\pm 1\%), \text{100fb}^{-1}$

Chi2 / ndf = 31.08 / 55
Normalization = 2.159$\pm$0.1322
Higgs mass = 120$\pm$0.01021
Gauss Width = 1.486$\pm$0.1363

$\sigma_{\text{MM}}=1.49\text{GeV}$

LCWS2000 A.Miyamoto
Beam energy spread in a bunch at $E_b=250\text{GeV}$ (JLC - A) changing RF phase. An initial spread of 1% (rms) at 10GeV has been added. Bunch-to-bunch, pulse-to-pulse fluctuation shall be less than ±0.1%.
Missing mass resolution and center-of-mass energy

\[
m_\text{MM}^2 = s - 2E_Z \sqrt{s} + m_Z^2
\]

\[
\Delta m_{\text{MM}} \sim \left( -2 \frac{\sqrt{s}}{m_{\text{MM}}} + \frac{m_Z^2}{p_\mu m_{\text{MM}}} \right) \Delta p_\mu
\]

(neglect \( \Delta \sqrt{s} \) and \( \Delta \cos \theta_{\mu^+\mu^-} \))

\[
\begin{array}{ccc}
\sqrt{s} & 300 \quad 250 & \text{GeV} \\
< p_t(\mu) > & 64 \quad 50 & \text{GeV} \\
\Delta p_\mu & 0.41 \quad 0.25 & \text{GeV} \\
\left( -\frac{\sqrt{s}}{m_H} + \frac{m_Z^2}{m_{\text{MM}} p_\mu} \right) & 3.9 \quad 2.8 & \text{GeV} \\
\Delta m_{\text{MM}} & 1.6 \quad 0.7 & \text{GeV}
\end{array}
\]

JIM

\[
\sigma_{\text{MM}} = 0.88 \text{GeV}
\]

\[
\sigma_{\text{MM}} = 1.06 \text{GeV}
\]

\[
\sigma_{\text{MM}} = 1.84 \text{GeV}
\]

LCWS2000 A. Miyamoto
\[
e^{+}e^{-} \rightarrow Zh, \ ZZ \rightarrow \mu\bar{\mu}X \quad \text{by JIM (JLC full simulation)}
\]

\[
\sqrt{s} = 250 \text{GeV}, \text{ISR+BS+}\Delta E_B(\pm 0.5\%), \ 100 \text{fb}^{-1}
\]

- \(zh\)
- \(ZZ\)

\(M_h = 120 \text{GeV}\)
## Detector R and D Status

### CAL Hardware Compensation

<table>
<thead>
<tr>
<th>R&amp;D items</th>
<th>Status and future R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tile-fiber</strong></td>
<td>test module: 1m x 1m x 7 λ, a tile of 20cm x 20cm</td>
</tr>
<tr>
<td><strong>Pb/Scinti. Config.</strong></td>
<td>optimum config.: 4mm^t/1mm^t for EM, 8mm^t/2mm^t for HAD by beam test at KEK(1–4GeV) and at FNAL(10–200GeV)</td>
</tr>
<tr>
<td><strong>Energy resolution</strong></td>
<td>HAD: σ/E=46.4/√E+2 % (43.6/√E+0 % for no shower leak), worse than the design value, to be invetigated.</td>
</tr>
<tr>
<td><strong>e-π separation (γ-π0)</strong></td>
<td>Pre-shower(PS) and Shower-maximum(SM) detector in front. [PS1,2: 3+3 layers of Pb/sci.(4/1mm), SM:sci.-strips of 1cm width (5mm^t). Typically, e/π=1400 (944) for energies of 100(75)GeV with ε_e=98% by [D=Σ zj \cdot E_j/E_{tot} and R_{PS2}=E(PS2)/E_{tot} ]</td>
</tr>
<tr>
<td><strong>Photo-detector (PD)</strong></td>
<td>operation in B= 2 – 3 Tesla.</td>
</tr>
<tr>
<td><strong>CAL</strong></td>
<td>Hybrid (H) PD – mid.gain (5,000), Lower temp. coeffi.</td>
</tr>
<tr>
<td><strong>PS/SM</strong></td>
<td>Vaccum Avalanche (VA)PD – hi gain(&gt;50,000), hi temp. coeffi. , single γ count, SM: APD or EB-CCD(most preferred)</td>
</tr>
<tr>
<td><strong>Segmentations</strong></td>
<td>need optimization; both in tansverse and longitudinal directions. [4cm x 4cm x 3 z (24mrad,EM), 12cm x 12cm x 4 z(72mrad,HAD)]</td>
</tr>
</tbody>
</table>
JLC Calorimeter

Tile-Fiber structure

Optical Fiber to Photo-Detector

r=1.6m

r=1.86m

r=3.4m

Optical Fiber to Photo-Detector

PSD or EM1

SMD

Scintillator Strip 5mm

Optical Fiber to Photo-Detector

EM1

EM2

EM

HAD

72 mrad

H1

H2

H3

H4

24mrad

2.0λ

1.75λ

1.5λ

1.25λ
Figure 13.23: Schematical drawing of PSD (left) and SMD (right).
**Figure 13.28:** Schematic view of the HPD structure.
Hardware Compensation with a configuration of lead and scintillator.

8mm Lead and 2mm scintillator
3) Proof of Performance

Beam tests done at KEK (1-4GeV) and at FNAL (10-200GeV) to prove:

a) **Energy Resolution** / Gaussian Response / Hardware Compensation
b) **Linearity** / Dynamic Range
c) **Tower Boundary Uniformity**
d) **$e/\pi$ separation** capability

![Schematic View of Hadron Calorimeter test module with Tile/Fiber configuration](image)

- 2mm-Sci + 8mm-Lead
- 130 layers in total
- 5 x 5 tower structure
- 20cm x 20cm cell size
Beam Test Results at KEK and FNAL

- **Energy Resolution**
  
  \[ \pi^{-} : \frac{\sigma_E}{E} = 45.9\% \pm 1.5\% \]

  to be investigated toward the design value of 40%.

- **Linearity**

  \[ \text{Measured Energy (GeV)} \]

- **Deviation**

  Hardware compensation works.
e-π separation by calorimeter
Figure 13.1: An example of reconstructed-mass resolution for $W$ with kinematical fit for the reaction $e^+e^- \rightarrow W^+W^-$ at $\sqrt{S} = 400$ GeV, obtained by quick simulation with the baseline detector of 2Tesla version.

<table>
<thead>
<tr>
<th>Contribution</th>
<th>Width (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural width of $W$</td>
<td>$\sim 1.6$</td>
</tr>
<tr>
<td>Neutrino escape</td>
<td>$\sim 0.8$</td>
</tr>
<tr>
<td>CDC momentum resolution</td>
<td>$\sim 1.3$</td>
</tr>
<tr>
<td>CAL energy resolution</td>
<td>$\sim 1.2$</td>
</tr>
<tr>
<td>Cluster-track association</td>
<td>$\sim 1.9$</td>
</tr>
<tr>
<td>Jet clustering</td>
<td>$\sim 1.1$</td>
</tr>
<tr>
<td>Total Width</td>
<td>$\sim 3.3$</td>
</tr>
</tbody>
</table>

Table 13.1: Various contributions to the width of reconstructed $W$ mass for the reaction $e^+e^- \rightarrow W^+W^-$ at $\sqrt{S} = 400$ GeV.
Model (a) and (b) at B= 2T and 3T, respectively
### Background tolerance

#### (1) CDC  10 % occupancy / train

<table>
<thead>
<tr>
<th>$r_{\text{min}}$</th>
<th>B</th>
<th>2 tesla</th>
<th>3 tesla</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 cm</td>
<td>△</td>
<td>1.2 k</td>
<td>0.12 k</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.4 k)</td>
<td>(0.37 k)</td>
</tr>
<tr>
<td>1.8 cm</td>
<td>○</td>
<td></td>
<td>0.72 k</td>
</tr>
<tr>
<td>1.5 cm</td>
<td>×</td>
<td>4.2 k</td>
<td>2.6 k</td>
</tr>
</tbody>
</table>

Values in ( ) are those of JLC-Y (high luminosity).

#### (2) VTX  1hit / mm$^2$ / train

<table>
<thead>
<tr>
<th>$r_{\text{min}}$</th>
<th>B</th>
<th>2 tesla</th>
<th>3 tesla</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 cm</td>
<td>○</td>
<td>0.9</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.8)</td>
<td>(1.0)</td>
</tr>
<tr>
<td>1.8 cm</td>
<td>△</td>
<td></td>
<td>1.6</td>
</tr>
<tr>
<td>1.5 cm</td>
<td>×</td>
<td>4.3</td>
<td>3.6</td>
</tr>
</tbody>
</table>

4.3 and 2cm$\phi$ beam pipes for $r_{\text{min}}$=2.5, 1.8 and 1.5 cm, respectively.
New Configurations at IR for "3T" model

Model (c)

Model (d)
Background hits per beam crossing

<table>
<thead>
<tr>
<th>model</th>
<th>B</th>
<th>L*</th>
<th>Mask</th>
<th>min. θ</th>
<th>VTX</th>
<th>CDC(γ)</th>
<th>CDC (n)</th>
<th>CAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T</td>
<td>m</td>
<td>mrad</td>
<td>mrad</td>
<td>hits/cm²/BX</td>
<td>hits/BX</td>
<td>hits/BX</td>
<td>MeV/BX</td>
</tr>
<tr>
<td>a</td>
<td>2</td>
<td>2</td>
<td>150–200</td>
<td>50</td>
<td>0.7</td>
<td>2</td>
<td>30</td>
<td>600</td>
</tr>
<tr>
<td>b</td>
<td>3</td>
<td>2</td>
<td>150–200</td>
<td>50</td>
<td>0.4</td>
<td>1</td>
<td>2</td>
<td>900</td>
</tr>
<tr>
<td>c</td>
<td>3</td>
<td>2</td>
<td>70–100</td>
<td>50</td>
<td>0.4</td>
<td>2</td>
<td>2</td>
<td>900</td>
</tr>
<tr>
<td>d</td>
<td>3</td>
<td>4.3</td>
<td></td>
<td>22</td>
<td>0.4</td>
<td>1</td>
<td>0.1</td>
<td>30</td>
</tr>
</tbody>
</table>

VTX: track density at the innermost layer (r=24mm)
Support tube R&D

Prototype 80cm long
(specimen)

2 sets

Laser

Geophone

G-sensor

Monitor

FFT

Data Logger

PC

Exciter

1Hz ~

Prototype 80cm long
(specimen)
Requirements for the Pair Monitor

- Detect a few 100 MeV electrons
- 30 hits/mm²/train
- ~50 kRad/year
- ~70 keV threshold to reject X rays.
- Identification of bunch in a train.
- Cover a circular area.

- Rate too high for a Si strip detector.
- CCD does not have TDC for each pixel.
- Active pixel sensor.

Use 100 x 100 mm² pixel.
TDC on each pixel.
Gating to reduce occupancy.
Pixel Beam Profile Monitor
H. Yamamoto et al., University of Hawaii

The sensor arrangement; the top side faces the IP.

One 'segment' ; the bottom side faces the IP.

3D Pixel
1. Fast charge collection
   < 1 nsec : bunch separation

2. Radiation hard
   >>50kRad/year, $10^7 n/cm^2/year$

3. Flexible geometry

4. Active edge

Schematic diagram of the 3D pixel concept
The layout of a trapezoidal prototype with 100µm pitch currently in fabrication at CIS of Stanford.
Possible Timing Circuit

Timing is defined by a low-threshold discriminator. Hit is defined by the high-threshold.

- Latch a counting gray code bus.
- TDC value stored on each pixel (~ 8 bits)
- Read-out time ~ 3.5 ms.

Alternative: $V_{ramp}$ stored on a capacity in each pixel.