LC Calorimeter Ideas and R&D Opportunities

Ray Frey, U. Oregon
SLAC, May 31, 2002

• Physics implications
• The environment
• The “energy flow” concept
• Current ideas and plans
  – Europe
  – Asia
  – N. America
• Critical R&D (my view)

\[ e^+e^- \rightarrow t\bar{t} \rightarrow 4 \text{jets} \]
500 GeV, SD detector
Physics: Jets!

- Complementarity with LHC:
  LC should strive to do well what LHC finds problematic

- Primary goal: Uncover the nature of electroweak symmetry breaking (Higgs, supersymmetry, extra dimensions, or “something else”)
  - e.g. Higgs decays to quarks important to measure well
  - May not always be possible to rely on e+e- beam constraints
    - e+e- → WW/ZZ → 4 jets

- Will get excellent results for leptons, photons, missing energy “for free”
$e^+e^- \rightarrow W W \nu\nu, \quad ZZ \nu\nu$

H. Videau
• LHC Study: Contributions to dijet mass resolution
• $Z \rightarrow JJ$. $dM/M \sim 13\%$ without FSR.

FSR is the biggest effect. The underlying event is the second largest error (if cone $R \sim 0.7$). Calorimeter resolution is a minor effect.

⇒ At the LC, detector resolution can have a bigger impact on jet physics
The Environment

"clean!"

but...

Low-p<sub>T</sub> pairs

1. Requires large (solenoidal) B field: 3-5 T
2. Bunch structure: bunches in trains
   - TESLA: 300 ns Xs in 1ms trains at 5 Hz
   - NLC/JLC: 2ns Xs in 300 ns trains at 180 Hz
In e+e-, jet reconstruction done with tracker aided by calorimeter (compared with calorimeter-only jet reconstruction)
And for large B, calor.-only becomes worse

\[ \text{SD detector, } e^+e^- \rightarrow q\bar{q}, \sqrt{s} = 200 \text{ GeV} \]

Ideal calor. + tracking \[ \sigma(M_{jj}) = 2.6 \text{ GeV}/c^2 \]
Ideal calor. only \[ \sigma(M_{jj}) = 9.2 \text{ GeV}/c^2 \]
Energy Flow

1. Charged particles in jets more precisely measured in tracker

2. Typical multi-jet event:
   - 64% charged energy
   - 25% photons
   - 11% neutral hadrons

- Use tracker for charged
- Calorimeter for neutrals
- Must locate and remove charged calor. energy
• Ignoring neutral hadrons, ideal calor.: 
  \[ h/e \rightarrow 0 \]

• Reality: separate charged/neutral with **dense, highly-granular** EM and HAD 
  \[ \Rightarrow \] An “Imaging Calorimeter”

• Figures of merit:
  – EM: \( \text{BR}^2 / R_m \) large 
  – Transverse seg.\( \sim R_m \) 
  – \( X_0 / \lambda_l \) small

• Alternative viewpoint (JLC): use compensating calor. (neu. hadrons)

\[ \tau \rightarrow \rho \nu \rightarrow \pi^+ \pi^0 \nu \]
**ECal**: Si/W a natural possibility
- \( R_m = 9 \) mm
- Easily segmented
- Used successfully in Lum. monitors at SLC and LEP
- Si/W Energy Flow detector by “NLC Detector Group”, Snowmass 96
- \(~20\) long. layers; \(~1000\) m\(^2\) of Si
- Much progress in Europe -- by ‘99, the TESLA standard
- Main issue: Si cost (~70% of ECal total)

**HCal**: Several possibilities being considered
- Scint. Tiles
- “digital” Hadron Calor.
- with RPCs?

**Alternative** (JLC): 4:1 Pb/scint-tile sandwich
- Sufficient segmentation?
Moore's Law for Silicon Detectors

<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si Area [m$^2$]</td>
<td>230 (CMS)</td>
<td>2,000</td>
</tr>
<tr>
<td># of Channels</td>
<td>10M (CMS)</td>
<td>100M</td>
</tr>
<tr>
<td>Cost [$/cm$^2$]</td>
<td>5 (CMS)</td>
<td>&lt; 2</td>
</tr>
</tbody>
</table>

Silicon Area [m$^2$] vs. Cost/Area of Single-sided Silicon Strip Detectors

Cost/Area of Single-sided Silicon Strip Detectors (double-sided factor 2.5 higher)

Year

Year
What determines the transverse segmentation?

- $BR^2$ and $R_m$
- And the physics:

\[ e^+e^- \rightarrow t\bar{t} \]

1) Extrapolate Charged tracks to the Cluster radius,
2) Associate the nearest track to the cluster

M. Iwasaki
**Digital HCal**

- Sufficiently small segmentation → 1 bit readout (2?)
- Use cheap, highly-segmented detectors

---

**Single charged pions →**

H. Videau, LPHNE-EP
What jet resolution can be achieved?

- TESLA studies: $\approx 30\% / \sqrt{E_{\text{jet}}}$ using current hybrid full simulation and reconstruction

- What is the best possible?

$$\sigma_{E_j}/E_j = 0.15/\sqrt{E_j}$$
EFlow also useful at had. colliders (<VLHC) with sufficient segmentation:

**Using Tracks (#5) Resolution & $E_T$ Scale**

**Resolution**

- 20GeV: 24% → 14%
- 100GeV: 12% → 8%

**$E_T$ Scale**

< 2% in 20-20GeV

---

0: no correction (calorimeter only)  
1: calo response - simple average  
2: calo response – library  
3: full correction (library of response, track-cluster match, out-of-cone tracks)  
4: out-of-cone tracks correction only