LC Calorimetry: Overview

Ray Frey, U. of Oregon
Chicago LCW, Jan 7, 2002

- Present Ideas: the Energy Flow Concept
- How well can one do?
- Excellent Jet Reconstruction: Physics Case
- Current Calorimeter Concepts/Designs
- Work to be Done …

Goal: See if we can build a detector which is much better than the present generation of outstanding $e^+e^-$ detectors.
Energy Flow

1. Charged particles in jets more precisely measured in tracker
2. Typical multi-jet event comp:
   – 64% charged energy
   – 25% photons
   – 11% neutral hadrons

- Use tracker for charged
- Calorimeter for neutrals
- Requires dense, granular cal. to separate and id. each particle
  - FoM: BR²/Rm (EM Cal.)

Additional benefits:
- Exc. electron, photon position
  → Non-pointing photons
- A muon tracker

Question:
How good (and costly) does it have to be?
• Si/W Energy Flow det. proposed by “NLC Detector Group”, Snowmass 96
• Much progress in Europe
• By ‘99, the standard TESLA config.
• New: “digital” Hadron Calorimetry

• One point of view:
  – LC detectors will require large solenoidal B fields to achieve excellent vertexing and tracking
  – In this case, jet recon. with comp. calorimetry is poor
  ➢ So EFlow will be necessary.
  ➢ And if done well, promises to provide excellent jet recon., better than standard techniques.

\[ \tau \rightarrow \rho \nu \rightarrow \pi^+ \pi^0 \nu \]
**Digital HCal**

- Sufficiently small segmentation $\rightarrow$ 1 bit readout (2?)
- Use cheap, highly-segmented detectors
What determines the transverse segmentation?

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

$$e^+e^- \rightarrow t\bar{t}$$

M. Iwasaki
What jet resolution can be achieved?

- TESLA studies are giving $\approx 30\% / \sqrt{E_{\text{jet}}}$ using current hybrid simulation and recon.
- ALEPH achieved $\approx 80\%$
- Complete recon. using fully simulated events requires a big investment in tool and algorithm building.
  - ECal and HCal clustering, tracking, and pattern recognition
  - hypothesis testing/fitting
- What is the best possible?
- Assume perfect charged/neutral separation
- Use single-particle cal. resolutions for neutrals (talk by Bower/Cassell)
- Use tracker for charged

\[e^+e^- \rightarrow q\bar{q}\]
Multi-jet mass for more complicated events

- $e^+e^- \rightarrow ZZ \rightarrow 4q$
- SD detector

$\sqrt{s} = 350$ GeV
Compare Ideal Energy Flow with Ideal Compensating Calorimeter

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

**EFlow** \( \sigma(M_{jj}) = 2.6 \text{ GeV}/c^2 \)

**Comp Cal.** \( \sigma(M_{jj}) = 9.2 \text{ GeV}/c^2 \)
Given energy-momentum constraints in $e^+e^-$, do we really need superb jet reconstruction and/or resolution?

Physics List
(to be expounded and expanded)

- **ZH vs WW vs ZZ final states**
- **H→ZZ vs H→WW**
- **HHZ: Higgs self-coupling (Tesla)**
- **ttH (8 jets, 4 b-jets)**
- **t-chan WW vs ZZ (Tesla)**
- **Anomalous Couplings**
  - top→3 jets
  - WW→jets
- **SUSY**
  - Decay chain recon.
  - Non-pointing photons

\[ K_s^0 \rightarrow \pi^0 \pi^0 \rightarrow \gamma \gamma \gamma \]
Impact of the jet resolution on the physics programme

Parametrising \( \Delta E_{\text{jet}} = \alpha \sqrt{E_{\text{jet}}} \)

\[ e^+ e^- \rightarrow ZH H \quad 6 \text{ jets} \quad L=1 \text{ ab}^{-1} \]
\[ \alpha = 0.6 \quad \Rightarrow \quad 3\sigma \quad \alpha = 0.3 \quad \Rightarrow \quad 6\sigma \]

\[ e^+ e^- \rightarrow t\bar{t} H \quad \text{work in progress} \]

\[ e^+ e^- \rightarrow ZH, \quad Z \rightarrow q\bar{q}, \quad H \rightarrow WW^* \]
\[ \alpha = 0.3 \quad \Rightarrow \quad 0.6 \quad \Rightarrow \quad \text{loosing 45\% of L} \]

\[ e^+ e^- \rightarrow ZZ \nu\bar{\nu}, \quad WW \nu\bar{\nu} \]
\[ \text{in the separation } ZZ / WW \]
\[ \alpha = 0.3 \quad \Rightarrow \quad 0.6 \quad \Rightarrow \quad \text{loosing 40\% of L} \]

a lot more work to assess the effect on all the programme
$e^+e^- \rightarrow W W \nu\nu$, $ZZ \nu\nu$
• Build these “known” case
• But also be ready for the unknown!

– A major advantage of e^+e^- is access to all final states
– Difficult to recon./separate hadronic final states at hadron colliders
– Complementarity suggests we pursue this advantage. (And I believe we can, and we should.)
**W/Si EM Cal.**
- 2 sampling sizes: 2.8, 8.4 mm
- 20 layers; 1700 m^2^ total
- 15x15 mm^2^ segmentation
- 0.5 mm thick Si
- \(\approx 16\) channels per readout chip

**HCal – 2 options:**
1. **Digital**
   - 1x1 cm^2^ seg.
   - RPCs a possible detector
2. **Scint. Tiles**
   - 5x5 cm^2^ seg.
Detector slab
5 T
248 cm
1 cm “RPCs”, 1x1 cm²
2 cm S. Steel
34x
143 cm
0.1 mm Air
2 mm G10
120x
2 mm scint, 20x20 cm²
8 mm Pb
3 T
370 cm
HAD Cal
250 cm
2 mm scint, 20x20 cm²
8 mm Pb
0.4 mm Si, 5x5 mm²
2.5 mm W
112 cm
40x
1 mm scint, 5x5 cm²
4 mm Pb
SD

- High Quality Energy Flow (~TESLA)
- \( BR^2/R_m \approx 5 \) (~TESLA?)

Si/W EM:
- \( R_m \approx 9\text{mm}(1+\text{gap(Si)}/2.5\text{mm}) \)
- 5x5 mm² segmentation
- 2.5mm (0.71 \( X_o \)) sampling
- \( \sim 10^3 \text{m}^2 \text{Si} \)
  → Avoid \( N_{chan} \) scaling
  → Cost per cm² of Si

Granular HAD:
- "Digital"?
- 1x1 cm² segmentation
  → RPCs? Scint? aSi?
- 5 \( \lambda \) total depth

LD

Philosophy unclear:
- \( BR^2/R_m \approx 6 \)
- segmentation too coarse for EF?
- Pb/scint = 4/1 (compensation?)

Pb/Scint EM:
- Long: 4mm Pb/1mm scint
- Tran: 50x50 mm² scint tiles
- \( R_m = 20 \text{mm} \)
- Possibly add Sh. Max Si Layer?

Pb/Scint HAD:
- 8mm Pb/2mm scint
- 20x20 cm² tiles
- 7 \( \lambda \) total depth

What is best alternative to Si/W
- for large R calorimeter?
- for less costly calorimeter?
Event display
t-tbar event, 500 GeV
SD detector
GISMO simulation
LCD Root analysis framework
Work to be Done: Critical R&D

- **Physics Simulations**
  - Continue to build (or not) case for jet physics
  - Other: Leptons, isolated photons, …

- **General Concepts (Assuming EFlow)**
  - Alternative to Si/W ECal?
  - HCal
    - Digital or not?
    - HCal/Coil position
    - Standalone muon id?
  - Framework for cost/performance optimizations
  - For a low-E IR at Z-pole, forget all of this
• **Software:** Develop reconstruction tools

  ▶ Basic pattern recog.: Clustering, cal. tracking, merging, etc.

  ▶ Combined ECAL and HCAL

  ▶ Coordinate areas of emphasis with international partners

• **Hardware I:** Si detectors and readout

  ▶ Integration of detectors/readout

  ▶ Reduction of electronics channels

  ▶ Cost of detectors (Tesla: 3 Euros/cm²)

  ▶ Si gap size

  ▶ Transverse segmentation

  ▶ Dynamic range
• **Hardware II**: Digital HCal
  
  » What segmentation is required?
  
  » What detector type?
  
  » An inexpensive readout

• Coordinate our efforts internationally
Calorimetry Parallel Session, Tues 2:00 – 3:45

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Simulations/Calorimetry/Vertexing Joint Parallel Session, Tues 4:15 – 6:00

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