Digital Hadronic Calorimeter
Jet Reconstruction in a

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KEK, Japan
ACAT03

IHEP, Protvino, Russia
Anatoly Sokolov
Outline

- Particle Reconstruction
- DHCAL Resolution
- High granularity calorimeters
- Installation design

Programme for e+e- linear colliders ($\sqrt{s} \approx 90 \text{ GeV} - 1 \text{ TeV}$)

High level accuracy of jet reconstruction is demanded by physics
<table>
<thead>
<tr>
<th>Process</th>
<th>Final State</th>
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<tbody>
<tr>
<td>e+e-</td>
<td></td>
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<tr>
<td>e+e-</td>
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<tr>
<td>HHZ</td>
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<td>H11</td>
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<td>H11</td>
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<tr>
<td>W+M</td>
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<tr>
<td>W+M</td>
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<tr>
<td>(l+)Z</td>
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<td>(l+)Z</td>
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**Table:**

<table>
<thead>
<tr>
<th>f+E Non-pointing</th>
<th>Extra-dimension gMSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 fels, 10 fels</td>
<td>( \frac{x}{x} + \frac{x}{0} )</td>
</tr>
<tr>
<td>2 fels, 4 fels</td>
<td>( \frac{x}{x} - \frac{x}{0} )</td>
</tr>
<tr>
<td>6 fels</td>
<td>( \frac{x}{x} )</td>
</tr>
</tbody>
</table>

**Notes:**
- Polarity measurement
- Tagging
- Hermeticity of installation
- Identification of \( e^+/e^- \) pairs
- Precision measurement

**Physics Program for e+e- Linear Colliders**
Important: It is necessary to have a good separation of events with W, W, W, ZZ.

Searching for a new physics (SUSY, ...)

Looking for and study of H

Study of t-quark

Study of W (measurement of W, W scattering amplitudes)

(Z_0, Z_0) (LEP ~ 10^6)

Physics: precision measurement of Z_0 parameters (~10^6)

\[
\left(\int_{LEP} \frac{dp_t}{t} \right) \int_{t \sim 10^3} \frac{dp_b}{b} \int_{b \sim 90 \, \text{GeV}} \frac{dp_f}{f}
\]

New generation of e+e- linear colliders / 14 TeV

Physics program for e+e- linear colliders
equivalent to a loss of ~40% of an integrated luminosity

\[ \frac{a = 0.3 - 0.6}{\int_0^s} \]

\[ s = 800 \text{ GeV} \]

\[ ZZ \rightarrow W^+W^- + \ell^+\ell^- \rightarrow e^+e^- + \nu \]
The main uncertainty of a jet reconstruction gives an ambiguity of a separation of CDF2, ZEUS, ALPHE, ATLAS

\[ \sqrt{\sum_{i=1}^{n} (E_{i})^2} = \sqrt{0.5 \div 0.6} \]

\[ \sum_{i=1}^{n} (E_{i})^2 = 45 \cdot \sqrt{E} \]

\[ \sum_{i=1}^{n} (E_{i})^2 = 12 \cdot \sqrt{E} \]

\[ \sum_{i=1}^{n} (E_{i})^2 = 10 \cdot \sqrt{E} \]

It is necessary to reconstruct particles in jets (like in a bubble chamber)

\[ \sum_{i=1}^{n} (E_{i})^2 = \sqrt{E} \]

Jet momentums is measured as the sum of its components momenta of particles: 

\[ p_{T} = p_{T}(p_{\text{ch. part.}} + p_{\gamma} + p_{\text{nucl. hadr.}}) \]

This algorithm increases the precision of jets momenta measurement at 30%.

Energy-Flow algorithm
Proper resolution of DHCAL is practically the same as for the usual HCAL.

(Hi registers hits only, but don't measure signal amplitudes).

Henri Video (Ecole Polytechnique) - DHCAL

Ideal solution - uniform calorimeter (~ECALE) - but a high cost:

- High magnetic field (~4 T, TESLA).
- Compactness of calorimeters.
- Both calorimeters (ECALE, HCAL) should be placed in the magnetic field.
- High granularity of calorimeters.
- Absence of a dead material before calorimeters.
- High precision of track momenta measurement.
- Large length of charged tracks.

Installation design
24 X 0

ECAL (W/Si) - 40 layers, 24 X 0

B = 4 Tesla

15 X 0

Tesla
cell size = 1 cm x 1 cm

ECAL, DHCAL

$K^0_L, p_T = 50 \text{ GeV/c}$
$e^+e^- \rightarrow W^+W^-$

ECAL, DHCAL

cell size ~ 1cm x 1cm

$\sqrt{s} = 800$ GeV
Fe/Scint. HCAL - cell size 1cm x 1cm - 40 layers (0.367 / layer)
W/Si ECal - cell size 1cm x 1cm - 40 layers (30 x 0.4 x 0.1 x 1.2 x 0.4)

Simulation of interactions in ECal, HCAL (Tesla) - MOKKA package

Hadron energy reconstruction in a calorimeter
Reconstruction Resolution

Proper Resolution

HCal Resolution
calculation of a probability, that a cluster is an electromagnetic one.

4. Extracting of el-mag clusters.

3. Classical procedure of cluster finding in the each precluster:
   - Clustering
   - Gathering of hits in a cone ~ 10°, starting from the hit with a highest energy.
   - Pre-clustering of charged track hits:
     - Filtering of ECAL hits

PPD07 (Photon Finder Version 07) works with ECAL

 Formation of track clusters

Reconstruction

j-c. brient, p. mora de freitas, h. videau (ecole polytechnique, paris, france)

RepliC - Reconstruction Package for the Linear Collider

Particle Reconstruction
$\sqrt{s} = 800 \text{ GeV}$

$M + M \leftrightarrow e + e$
$\sqrt{s} = 500 \text{ GeV}$

$H \wedge e^+ e^-$
Generalization of the FCM algorithm

\[(\Lambda', X) f\]

- Modification of the objective function

- Using different distance functions

Fuzzy c-means algorithm (FCM) - generalization of the objective function

\[\left(\lambda, x\right) p \sum_{u} \sum_{o} \frac{1}{f} = (\Lambda', X) f\]

Hard c-means algorithm - minimizes of the objective function

\[\left(\lambda, x\right) p \sum_{u} \sum_{o} \frac{1}{f} = (\Lambda) f\]

Improving the clustering quality
Fuzzy Fuzzy

after filtering from reconstruction

MC
for each cluster
Fraction of cells collected

Angle between MC cluster and reconstructed one

Fuzzy
operation of DHCAL (NN, fuzzy logic, ...).

- It is necessary to create a software of a new generation to provide a successful

- A possible solution for a high granularity hadronic calorimeter is a digital HCAL.

- High granularity calorimeters could provide a desired jet reconstruction accuracy.

- The main uncertainty of a jet reconstruction gives an ambiguity of a separation

  \( \frac{1}{10} \sim 30^{\text{FWHM}} \)

- It is necessary to have an accuracy of jet energy reconstruction

  \( \frac{1}{10} \sim 1 \text{TeV} \)

- To realize a physics programme at e^+e^- colliders with energy \( \sqrt{s} \sim 1 \text{ TeV} \),

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Summary