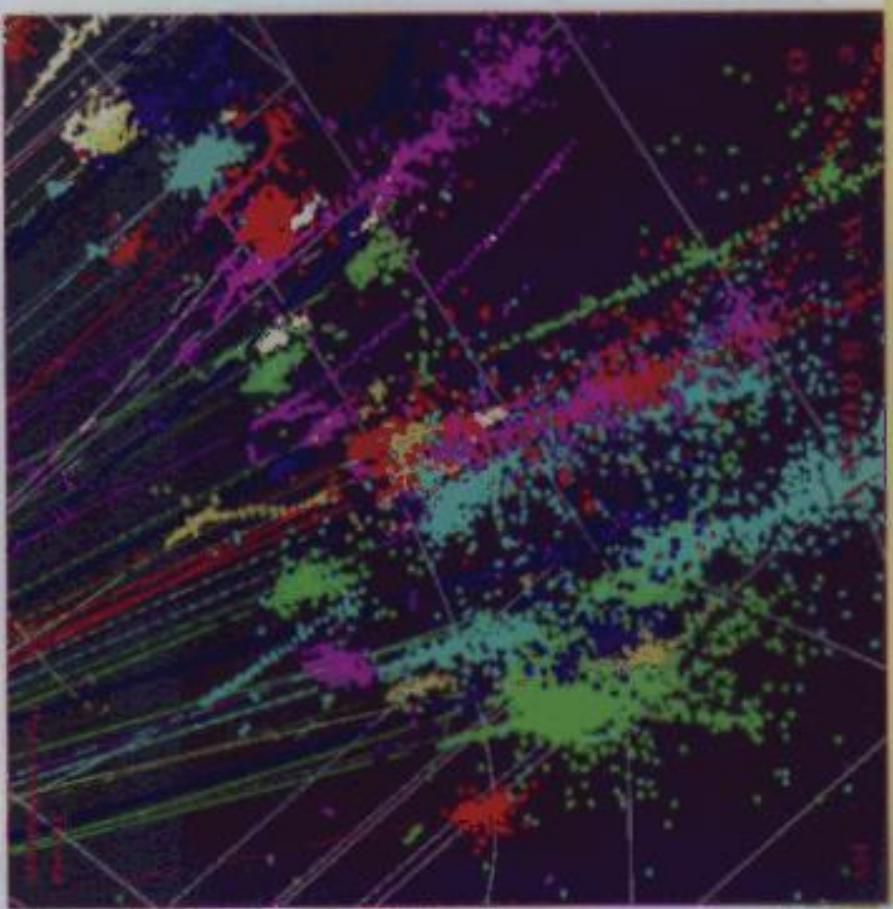


Jet Reconstruction in a Digital Hadronic Calorimeter

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KEK, Japan
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Outline

- High level accuracy of jet reconstruction is demanded by physics programme for e+e- linear colliders ($\sqrt{s} \sim 90 \text{ GeV} - 1 \text{ TeV}$).
 - Installation design.
 - High granularity calorimeters.
 - DHCAL resolution.
 - Particle reconstruction.

Physics Programme for e+e- Linear Colliders

Process	Final state	
$e^+e^- \rightarrow$		
$Z(\gamma)$	$2l, 2\text{ jets}$	• precision measurement of jets momenta
W^+W^-	$2l+2\text{ jets}, 4\text{ jets}$	
$t\bar{t}$	$l+4\text{ jets}, 6\text{ jets}$	
$t\bar{t}H$	8 jets	• identification of $e/\mu/h^\pm$
ZH	$2l+2\text{ jets}, 4\text{ jets}$	
ZHH	$2l+4\text{ jets}, 6\text{ jets}$	
$\tilde{\chi}_1^0\tilde{\chi}_1^0$	$jets+\#$ $6\text{ jets}+\#$	
$\tilde{t}\tilde{\bar{t}}$		and
$Rp-\tilde{\chi}_1^0\tilde{\chi}_1^0$	$2l+4\text{ jets}, 6\text{ jets}$	• b, c , tagging
$Rp-\tilde{\chi}^+\tilde{\chi}^-$	$2l+6\text{ jets}, 10\text{ jets}$	τ (polarization measurement)
GMSB	non-pointing γ	
Extra-dimension	$\gamma+\#$	

• b, c , tagging

τ (polarization measurement)

Physics Programme for e^+e^- Linear Colliders

New generation of e^+e^- linear colliders $\sqrt{s} \sim 90$ GeV – 1 TeV

$$\int L \cdot dt \sim 10^3 \text{ fb} \quad (\text{LEP} \quad \int L \cdot dt \sim .7 \text{ fb})$$

Physics: precision measurement of Z^0 parameters ($\sim 10^9 Z^0$) (LEP $\sim 10^6 Z^0$)
study of **W** (measurement of $W_L W_L$ scattering amplitudes)
study of t-quark
looking for and study of **H**
searching for a new physics (SUSY,...)

Important: it is necessary to have a good separation of events

with **WW, WZ, ZZ**

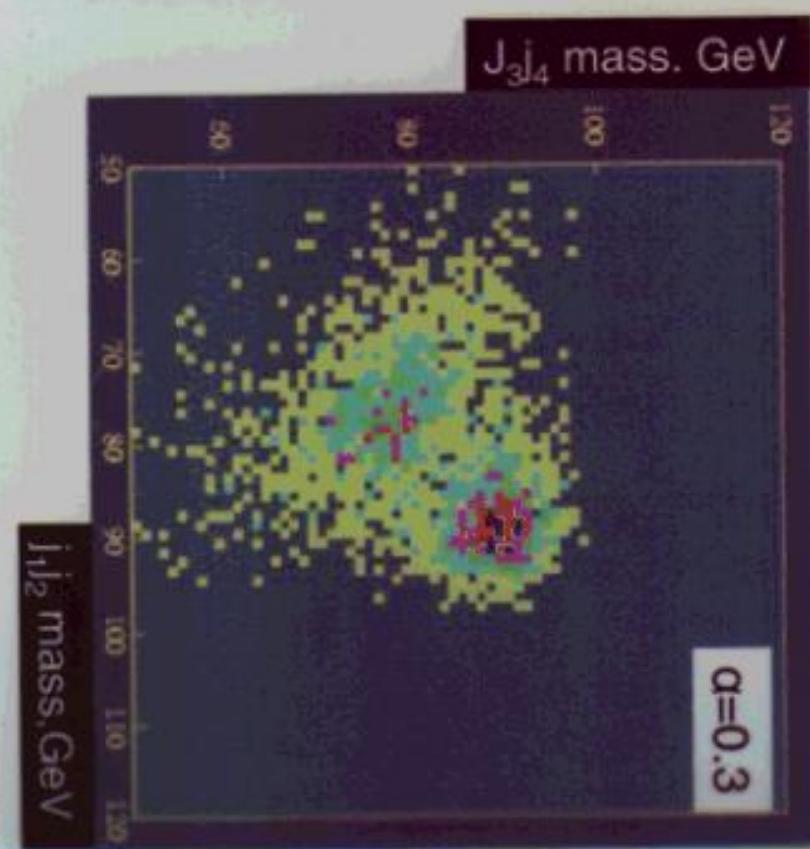
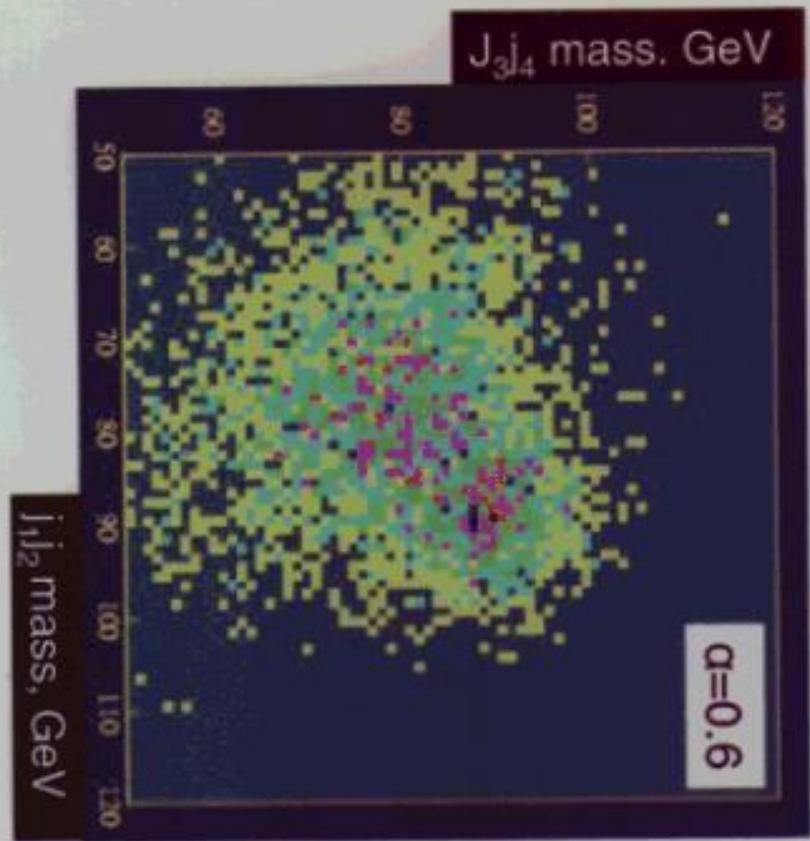
$e^+e^- \rightarrow \nu\bar{\nu}W^+W^-, \nu\bar{\nu}ZZ$

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

$$\sigma_{jet} = \alpha \cdot \sqrt{E_{jet}}$$

$$\alpha = 0.3 \rightarrow 0.6$$

equivalent to a loss of ~40% of an integrated luminosity ($10^4 WW, 10^4 ZZ$)



Energy-flow algorithm

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

Jet momentum is measured as the sum of its components momenta

$$P_{\text{jets}} = \sum (P_{\text{ch.part.}} + P_Y + P_{\text{neutr.hadr.}})$$

Part	65%	26%	9%
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It is necessary to reconstruct particles in jets (like in a bubble chamber)

$$\sigma_{\text{jet}}^2 = \sigma_{\text{ch.}}^2 + \sigma_\gamma^2 + \sigma_{h^0}^2 + \sigma_{\text{confusion}}^2$$

$$\sigma_{\text{ch.}} = 10^{-5} \cdot E^2$$

$$\sigma_\gamma = .12 \cdot \sqrt{E}$$

$$\sigma_{h^0} = .45 \cdot \sqrt{E}$$

$$\sigma_{\text{jet}}^2 \approx (0.14)^2 \cdot E_{\text{jet}} + \sigma_{\text{confusion}}^2$$

$$\sigma_{\text{jet}} = (0.5 \div 0.6) \cdot \sqrt{E_{\text{jet}}}$$

CDF2, ZEUS, ALEPH, ATLAS

The main uncertainty of a jet reconstruction gives an ambiguity of a separation of its particles (not a proper detector resolution)

Installation design

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

Ideal solution – uniform calorimeter (~ECAL) - but a high cost.

Henri Videau (Ecole Polytechnique) - **DHCAL**
(It registers hits only, but don't measure signal amplitudes).

Proper resolution of DHCAL is practically the same as for the usual HCAL.
But it is possible to construct DHCAL with a high granularity, which improve a particle separation in jets and an accuracy of jet reconstruction.

IV

Coupe possible du détecteur

VERSION 8 MODULES

Tesla

cm

600

500

400

300

200

100

0 100. 200. 300. 400. 500. 600. cm

Faisceau primaire

Coll

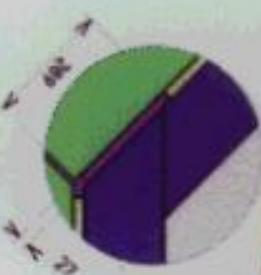
ICL

TPC

24 X_0

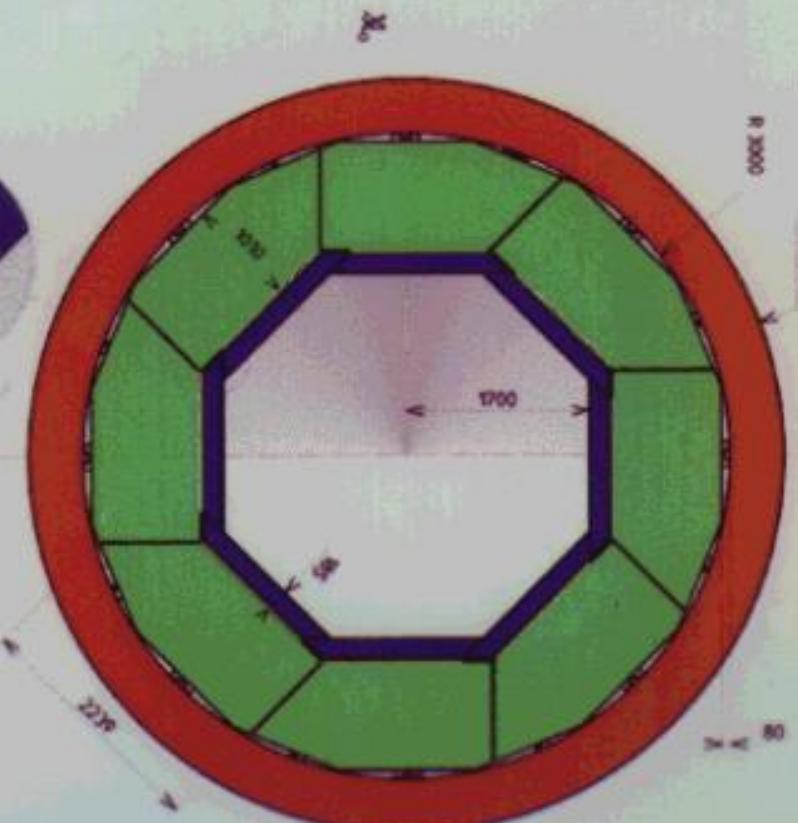
B = 4 Tesla

ECAL(W/Si) – 40 layers, 24 X_0



ENERGIE ELECTRONIQUE

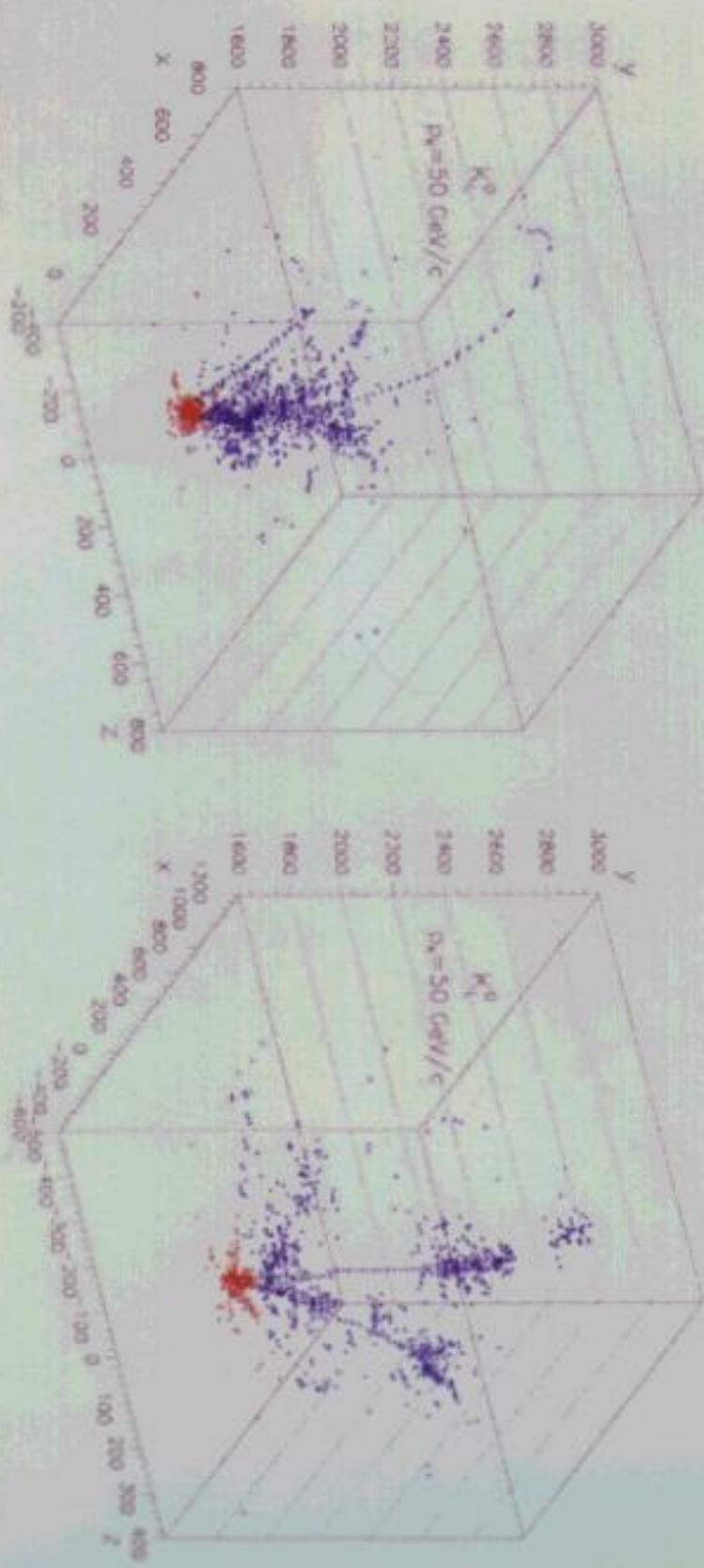
Le 12-10-1999



K_L^0 , $p_K = 50 \text{ GeV}/c$

ECAL, DHCAL

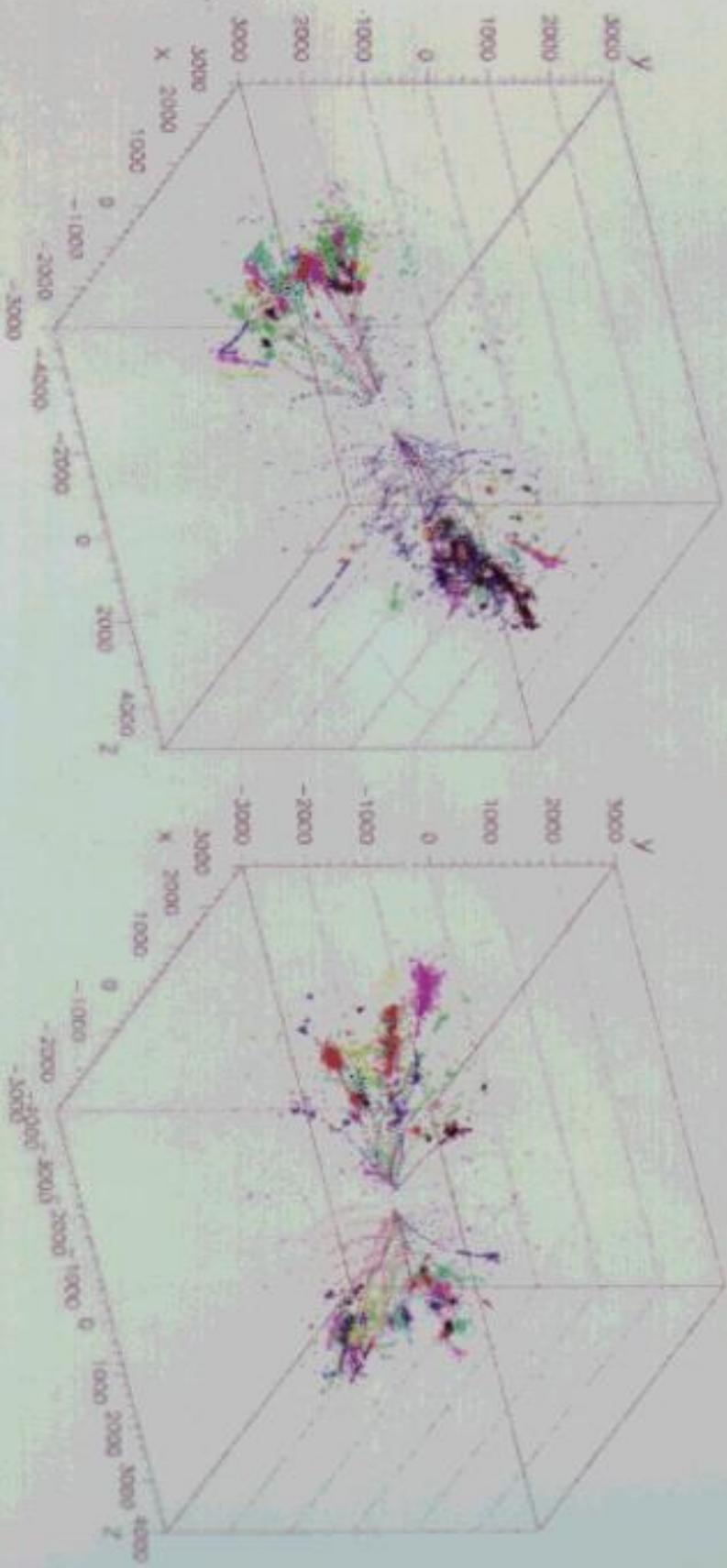
cell size ~ 1cmX 1cm



$e^+ e^- \rightarrow W^+ W^-$ $\sqrt{s} = 800$ GeV

ECAL, DHCAL

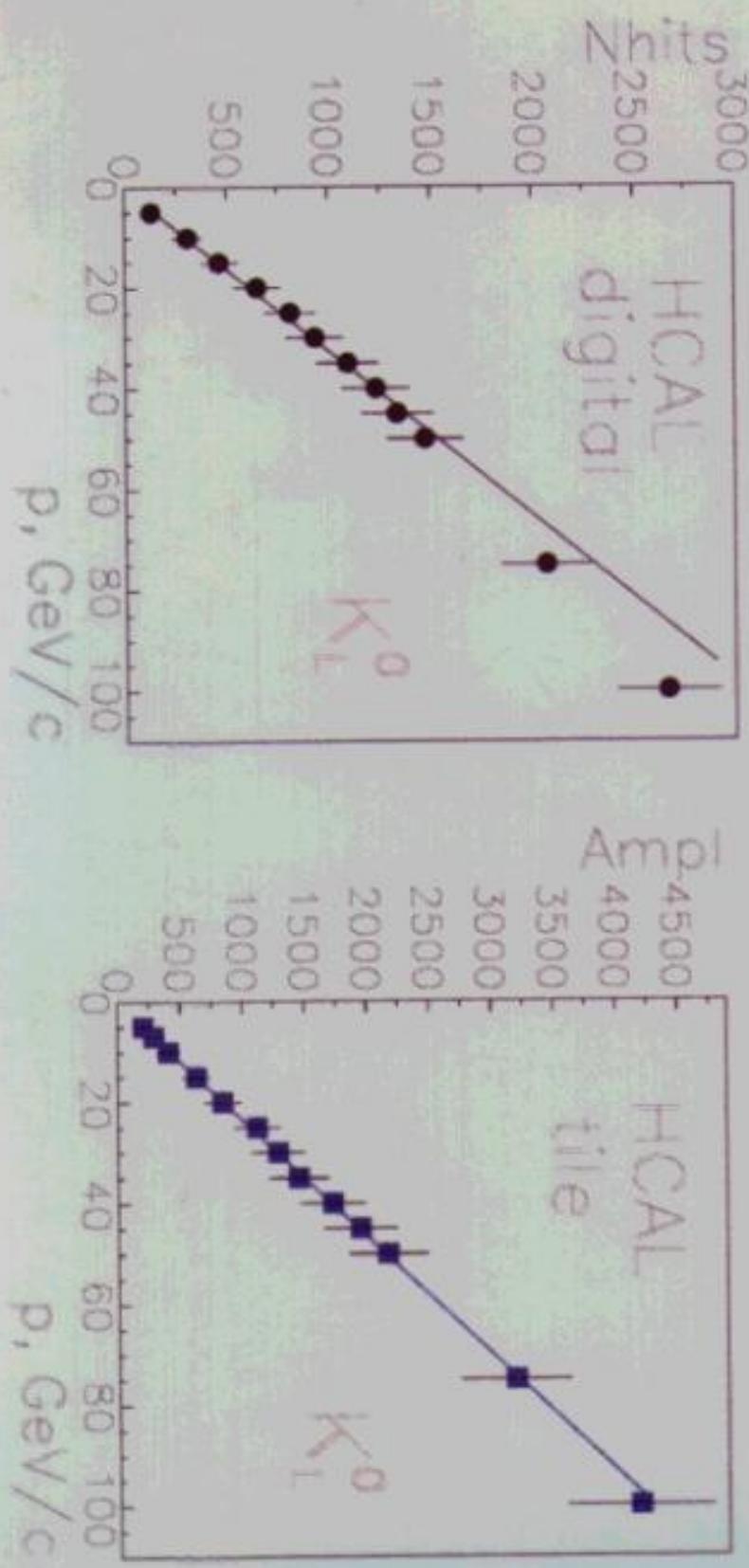
cell size ~ 1cm \times 1cm



Hadron energy reconstruction in a calorimeter

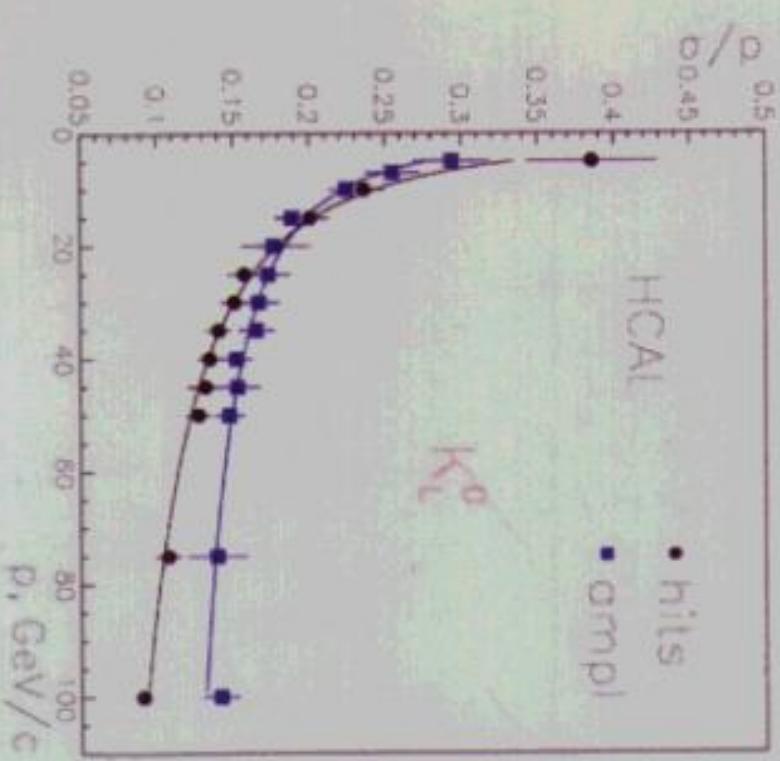
Simulation of interactions in ECAL, HCAL (TESLA) - MOKKA package

W/Si ECAL - cell size 1cm \times 1cm - 40 layers ($30 \times 0.4 X_0$, $10 \times 1.2 X_0$)
Fe/Scint. HCAL - cell size 1cm \times 1cm - 40 layers ($0.36 \lambda / \text{cm}^2$)

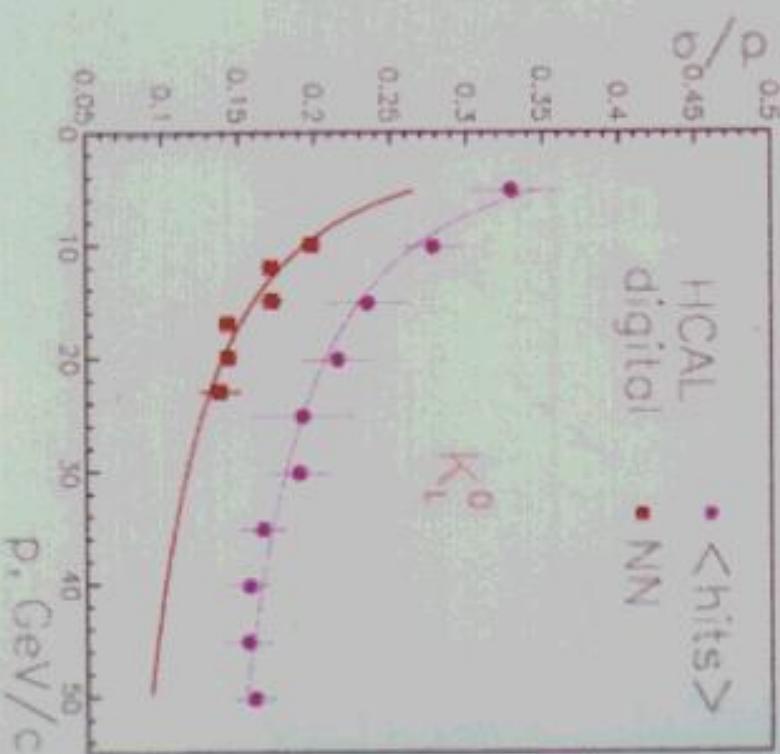


HCAL resolution

Proper resolution
of HCAL



Reconstruction resolution
of DHCAL



Particle reconstruction

REPLIC – REconstruction Package for the Linear Collider

J.-C. Brient, P. Mora de Freitas, H. Videau (Ecole Polytechnique, Paris, France)

γ reconstruction

PFD07 (Photon FinDer version 07) works with ECAL

1. Filtering of ECAL hits -
deleting of charged track hits;
2. Pre-clustering -
gathering of hits in a cone $\sim 10^0$, starting from the hit with a highest energy;
3. Clustering -
classical procedure of cluster finding in the each precluster;
4. Extracting of el.-mag. clusters -
calculation of a probability, that a cluster is an electromagnetic one
(15 cluster parameters are used).

Some results at 800 GeV on photons

$$e^+ e^- \rightarrow W^+ W^-$$

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

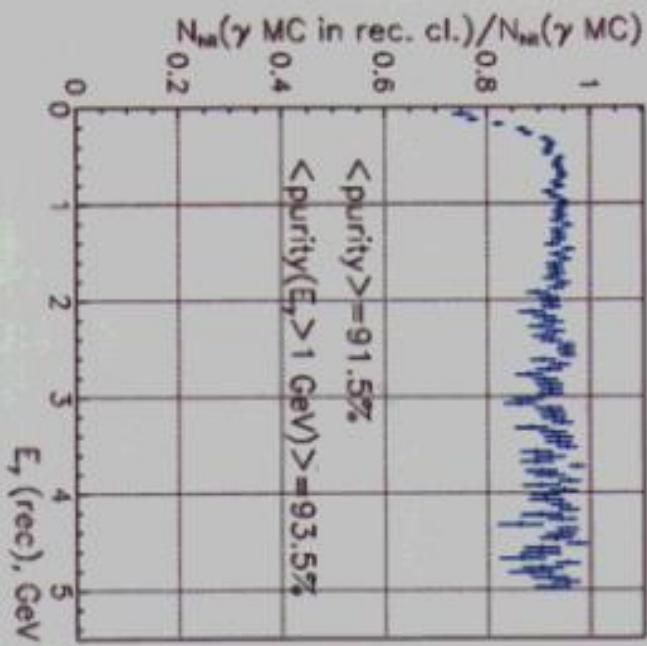
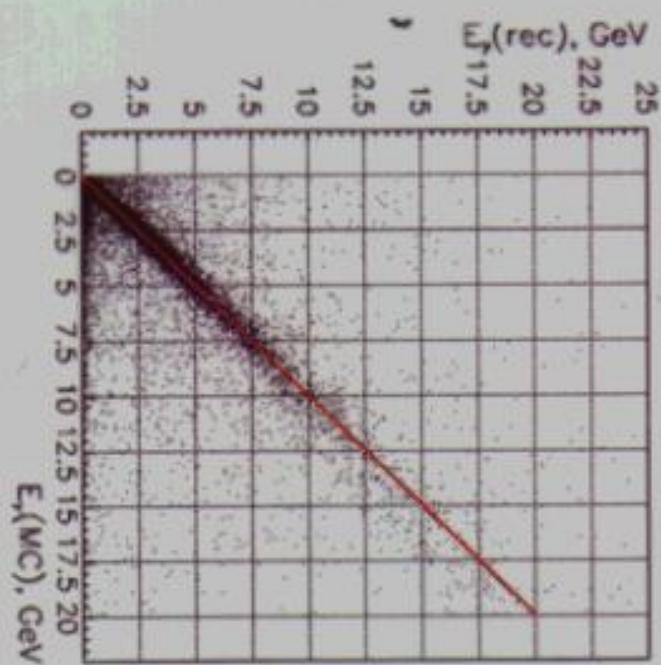
number of reconstructed γ 's
versus
number of generated γ 's

Photon reconstructed energy
versus
true energy

Results from REPLIC

$e^+ e^- \rightarrow ZH \rightarrow \nu \bar{\nu} H$ $\sqrt{s} = 500 \text{ GeV}$

Matching of reconstructed and MC γ
 $\min \cos \theta_{rec, MC}$



OK with a purity/efficiency

?

Improving of a clustering quality

Hard c-means algorithm – minimizes of the objective function

$$J(V) = \sum_{j=1}^c \sum_{i=1}^n d(x_i, v_j)$$

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

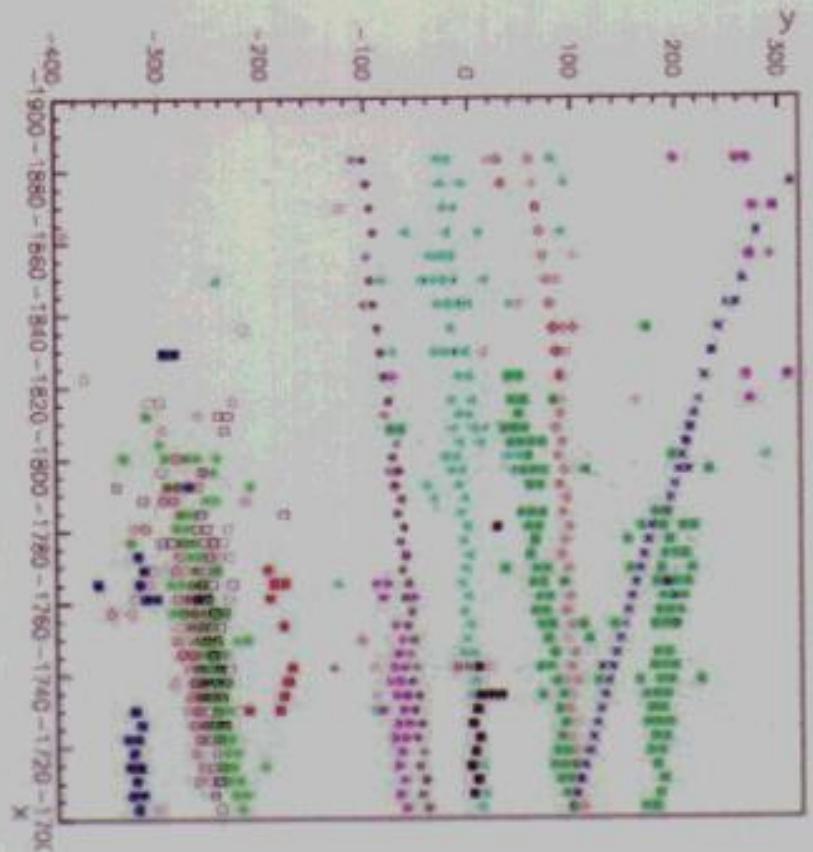
$$J(X, V) = \sum_{i=1}^c \sum_{j=1}^n u_{ij}^m d(x_j, v_i)$$

Generalization of the FCM algorithm

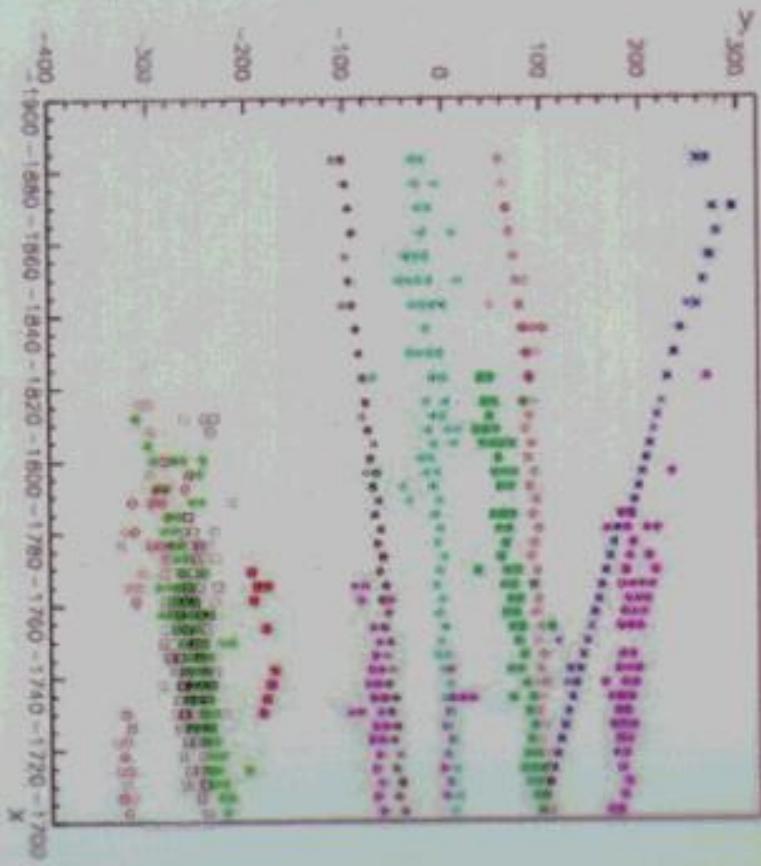
- using of different distance functions $d(x_i, v_j)$
- modification of the objective function $J(X, V)$

Fuzzy

from reconstruction
after filtering

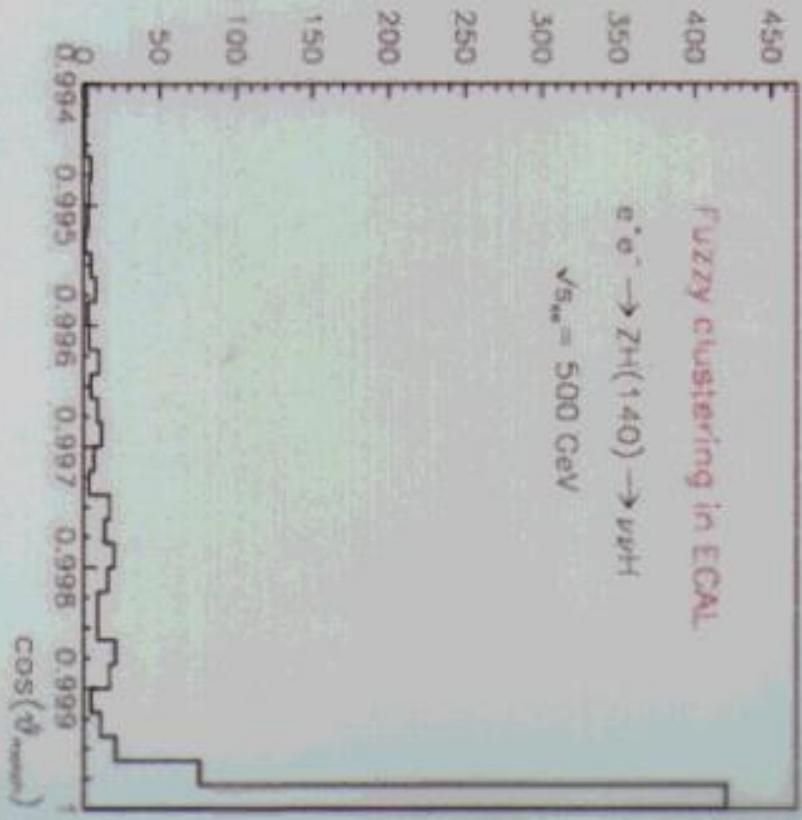
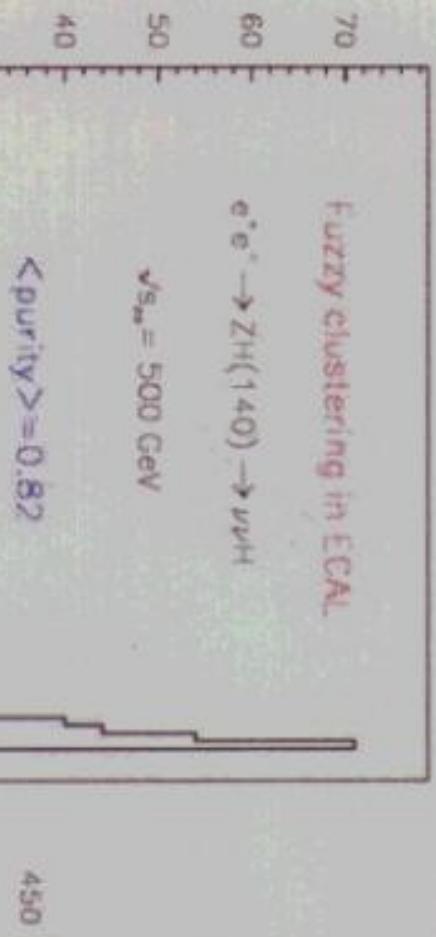


MC



Fuzzy

Angle between MC cluster and reconstructed one



Fraction of cells collected
for each cluster

Summary

- To realize a physics programme at $e^+ e^-$ colliders with energy $\sqrt{s} \sim 1 - 1 \text{ TeV}$ it is necessary to have an accuracy of jet energy reconstruction $\sigma_{jet} \sim .30\sqrt{E_{jet}}$ ($\sigma_{jet} \sim (.50-.60)\sqrt{E_{jet}}$ now).
- The main uncertainty of a jet reconstruction gives an ambiguity of a separation of its particles (not a proper detector resolution).
- High granularity calorimeters could provide a desired jet reconstruction accuracy.
- A possible solution for a high granularity hadronic calorimeter is a digital HCAL.
- It is necessary to create a software of a new generation to provide a successful operation of DHCAL (NN, fuzzy logic,...).