A Calorimeter for Energy Flow

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OUTLINE

Questions for a calorimeter design

- which final state should we consider ?
- Eflow and jet content
- Which Eflow ?
- Figure of merit for different Eflow
- Jet resolution dependence on the calorimeter performance
- Which technical solution for a calorimeter
- Geant-4 simulation for performance study
- Conclusion

Which final state for some physics processes

physic process $e^+e^- \to$	final state
$Z(+\gamma)$	2ℓ , 2 jets
W^+W^-	2ℓ+2 jets , 4 jets
$t\bar{t}$	ℓ+jets , 6 jets
$t\bar{t}$ H	8 jets
Z H	2ℓ+2 jets , 4 jets
Z H H	2ℓ+4 jets , 6 jets
$\tilde{\chi}^0_1 \tilde{\chi}^0_1$	jets + $\not{E}$
$\tilde{t}\, \bar{\tilde{t}}$	6 jets + $\not{E}$
$\not{R}$p - $\tilde{\chi}^0_1 \tilde{\chi}^0_1$	2ℓ+4jets , 6jets
$\not{R}$p - $\tilde{\chi}^+ \tilde{\chi}^-$	2ℓ+6jets , 10 jets
graviton	non-pointing photon
Extra-dimension	$\gamma + \not{E}$

WICH EFLOW ?

For example $e^+e^- \to$ Z h and h$\to$2 b-jets at $\sqrt{s} = 230$ GeV
2 jets with about 60 GeV each.

see figure

EFLOW type	< Especies/Ejet > (%)
Ch. track	65
Photon	27
Neutral hadron	8

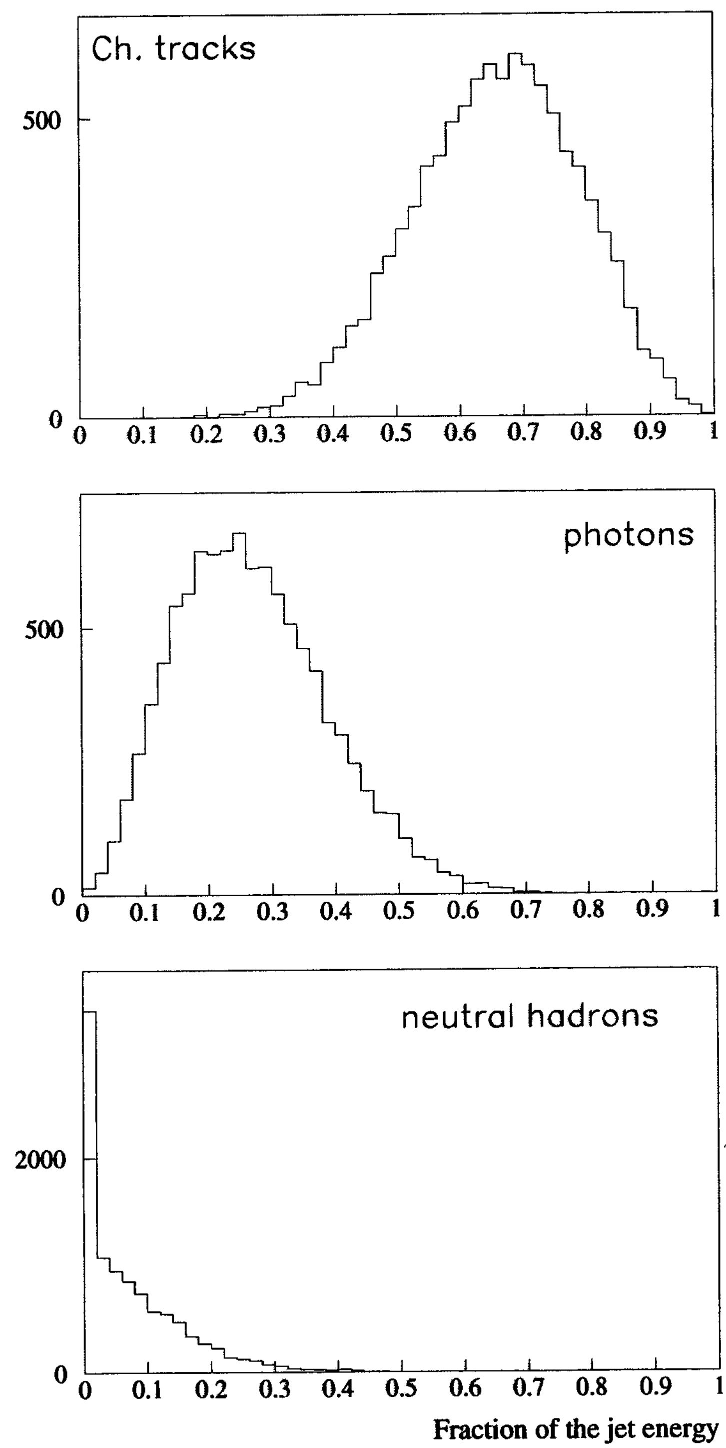
EFLOW using calorimetry only

- $\sim$ 7% of the "charged" energy *never* reach the calorimeter (for B=3T and R=170cm). Actually, they reach the calorimeter in the end-cap after multi-turn or they interact with the mask and are partially absorbed.
- The jet resolution $\Delta E_{jet}/E_{jet}$ is poor (see **figure**)
- Due to the B-field , the di-jet mass resolution is dramatically downgraded (a factor about 2.1) see **figure**

EFLOW using track information

- Identification and reconstruction of all EFLOW Objects
- With the energy distribution of the charged track, it is intrinsically better for jet energy resolution
- $\Delta\phi_{jet-jet}$ is much better (no B-field effect), consequently the di-jet mass is much better

Fraction of the jet energy per species



Black dots EFLOW using tracking info. with a "standard" detector

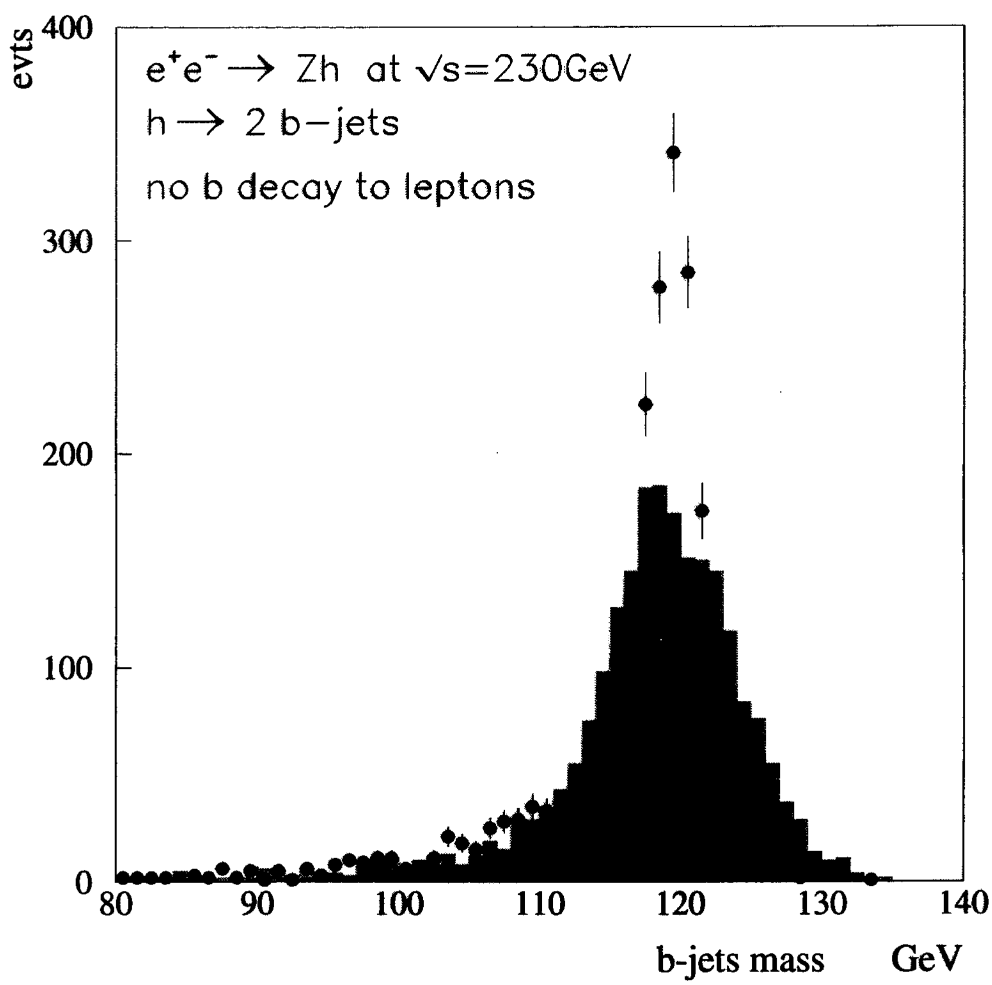
- $\Delta E/E = 15\%/\sqrt{(E)} \oplus 0.01$ for ECAL
- $\Delta E/E = 50\%/\sqrt{(E)} \oplus 0.02$ for HCAL

green histogram EFLOW using Calor. info. only with an improved detector

values taken from the CDR-DESY

- $\Delta E/E = 10\%/\sqrt{(E)} \oplus 0.006$ for ECAL
- $\Delta E/E = 40\%/\sqrt{(E)} \oplus 0.01$ for HCAL

Both jets inside barrel



Example with ALEPH

ECAL

- $19\%/\sqrt{E} \oplus 0.01$, 3x3cm towers ,3 segmentations in depth
- threshold for photon: $E\gamma$ >0.25 GeV , Dist.γ/track>2cm
- fraction of hadronic fake for a 10 GeV $\pi^{\pm}$ is 15%

(Important parameter if the Bfield is large)

HCAL

- with ECAL, $85\%/\sqrt{E}$ for hadron
- **BUT** No neutral hadron reconstruction

subtraction of charged energy linked to the same HCAL cluster with cuts on $E_{cluster} - E_{ch.track}$ and a threshold at 0.5 GeV

TRACKER

- $\delta p/p^2 \sim 6\ 10^{-4}$
- threshold 0.2 GeV with vertex constraint

jet resolution

$$\Delta E_j/E_j \sim 60\%/\sqrt{E_j}$$

The quality for this type of Eflow depends on

1 - The efficiency to tag all the Eflow object

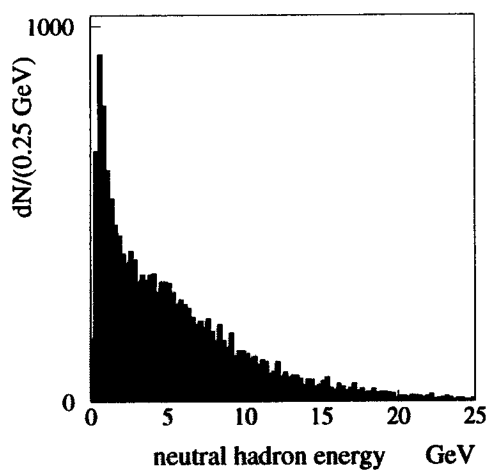
2 - The rate of "misidentification" ε(noise$\rightarrow$ Eflow)
noise coming from the debris of the charged hadronic interaction, coming from machine background, etc...

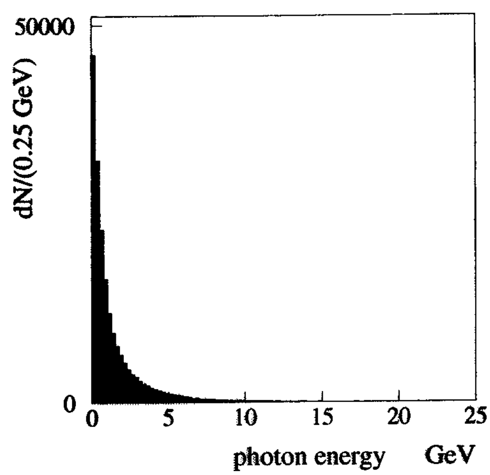
3 - The energy resolution for each species of Eflow object

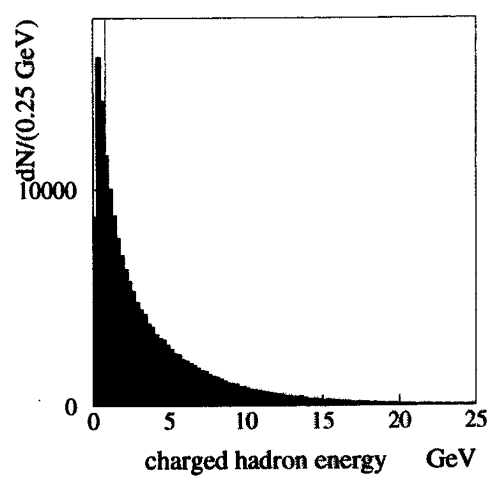
From point 1 and 2 , high 3-D granularity

Which energy region for each species ?

See the energy distribution for each species from 20K jets

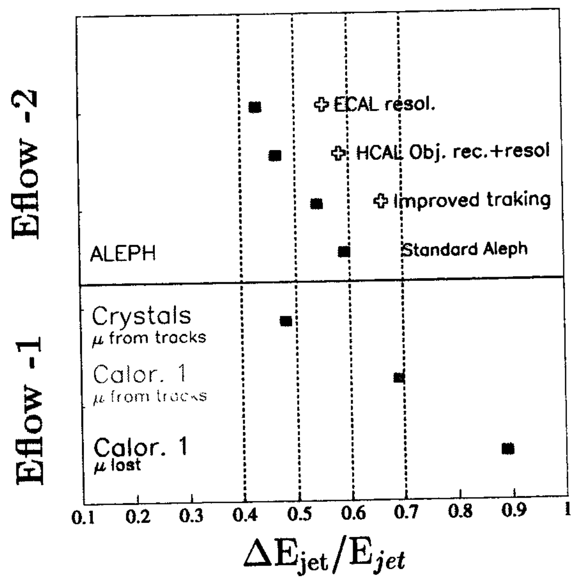


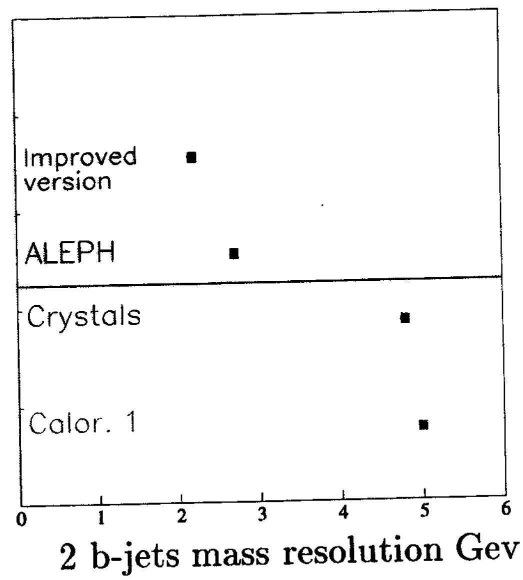




Some comparisons on jet resolution

<u>For the mass</u>
Higgs 120 GeV in 2 b-jets
no b decays with leptons
$\theta_{jet} > 15$ degres



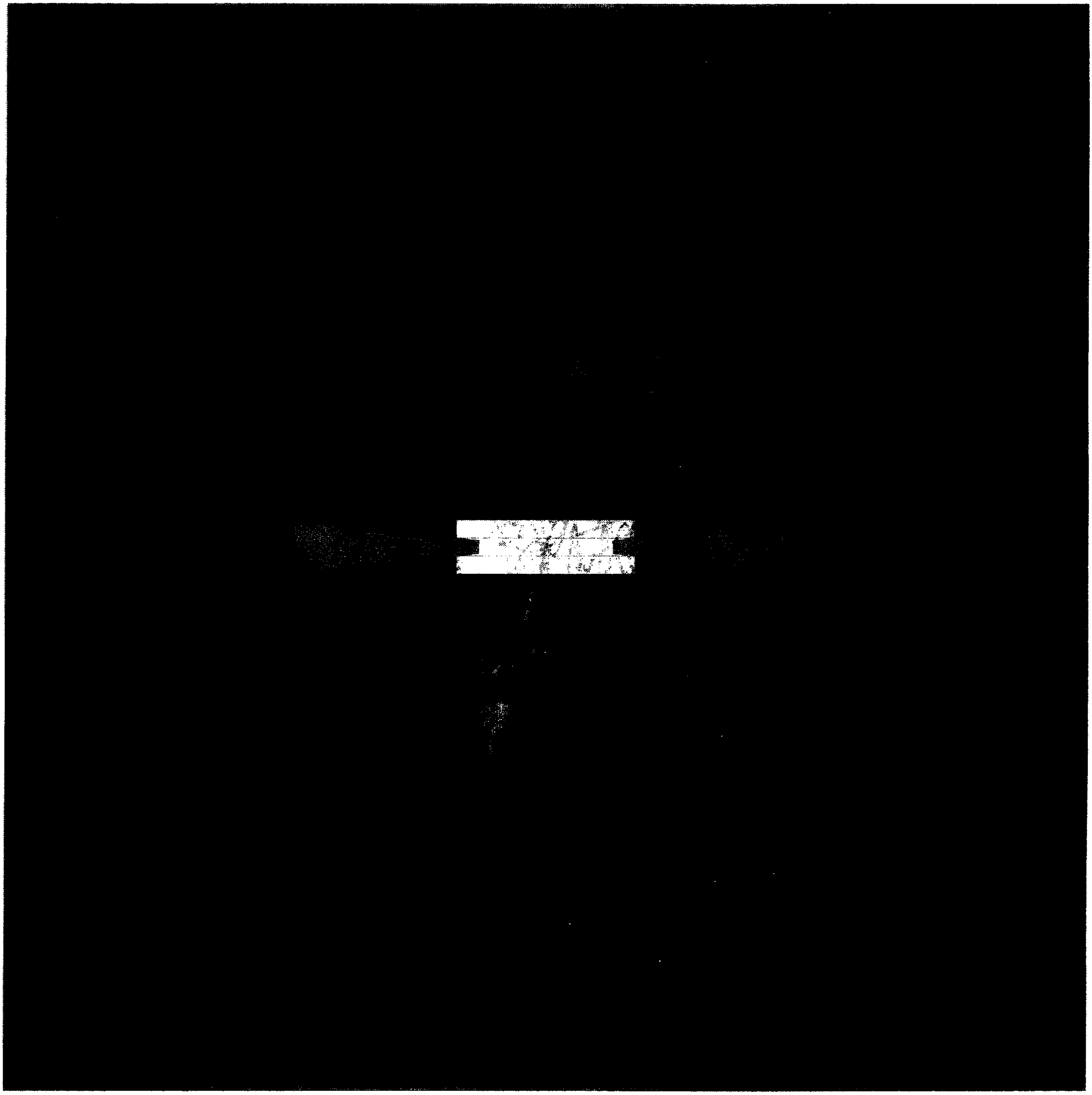


Eflow -1 is purely calorimetric
Eflow -2 is using the tracks info.

calor 1 :
ECAL $\Delta E/E = 0.10/\sqrt{(E)} \oplus 0.5\%$
HCAL $\Delta E/E = 0.40/\sqrt{(E)} \oplus 4.0\%$

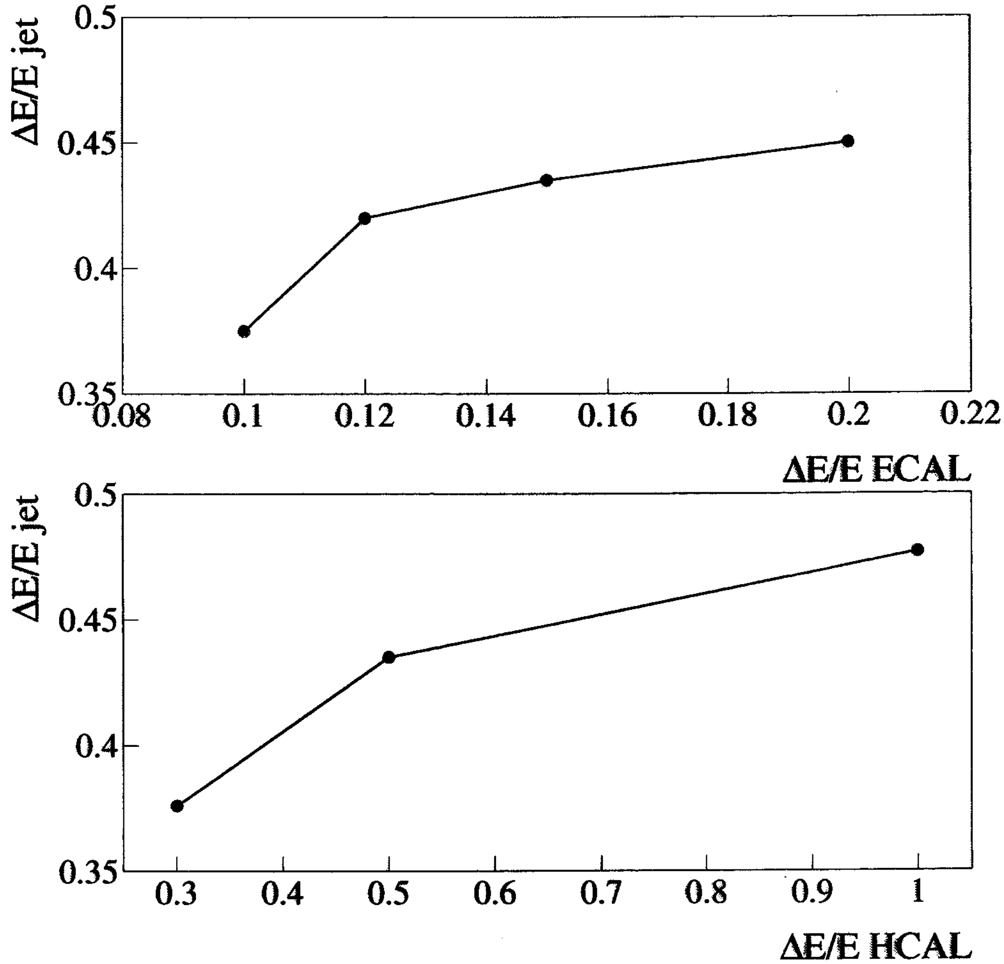
Crystals :
ECAL $\Delta E/E = 0.03/\sqrt{(E)} \oplus 0.5\%$ "a la CMS" barrel
HCAL $\Delta E/E = 0.40/\sqrt{(E)} \oplus 1.0\%$

final ALEPH improved version :
ECAL $\Delta E/E = 0.15/\sqrt{(E)} \oplus 1.0\%$
HCAL $\Delta E/E = 0.50/\sqrt{(E)} \oplus 1.0\%$ BUT HCAL obj. reconstruction
Tracking "a la CDR ECFA/DESY"



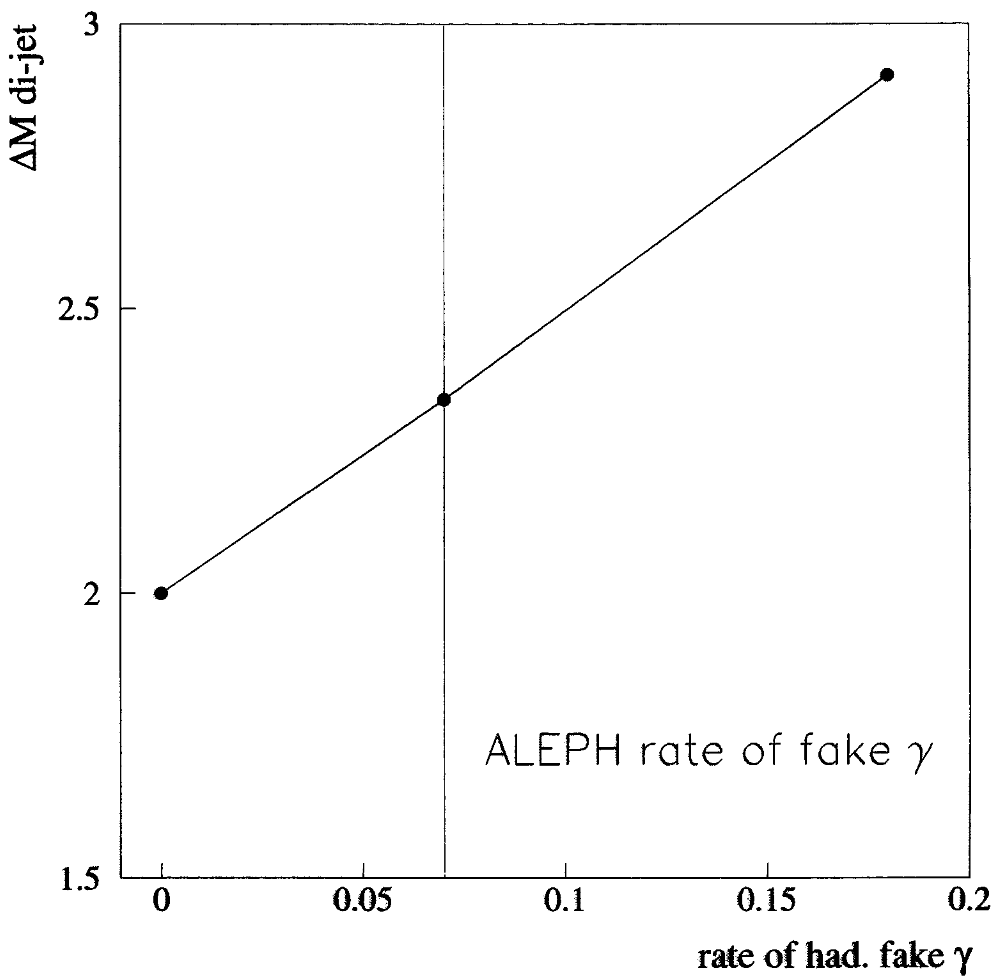
Variation with calorimeter resolution

polar angle of the jet > 15 degrees for Eflow type 2



WARNING from hadronic fake photon

the rate of "hadronic " fake photon is crucial for the di-jet mass resolution (again , 2b-jets, no b decays with lepton)
define the rate as the average value of Nfake/Ncharged



some important numbers

R_{ECAL} =170cm and B=3T

$e^+e^- \rightarrow$ Z h and h $\rightarrow$ 2 b-jets at $\sqrt{s}$ = 230 GeV

Photon energy in GeV

processes	E<0.2	E<0.5	E<1.
h→ 2 jets	20%	40%	60%

distance γ/closest charged track

processes	d<2cm	d<10cm	d<20cm
h→ 2 jets	0.4%	16%	43%

$e^+e^- \rightarrow$ 2 jets, $\tau^+\tau^-$ at $\sqrt{s}$ = 800 GeV

Photon energy in GeV

processes	E<0.2	E<0.5	E<1.
Z→ 2 jets	19%	30%	41%

distance γ/closest charged track

processes	d<2cm	d<10cm	d<20cm
Z→ 2 jets	11%	26%	41%
$\tau^+\tau^-$	36%	91%	97%

↑

WARNING for electron ID.

distance γ/closest neutral hadron

processes	d<5cm	d<10cm	d<20cm
Z→ 2 jets	9%	15%	21%

Key points for a calorimeter dedicated to this type of EFLOW

General comment:

- The e/π ratio is not important

ECAL

- Resolution
- Reconstruction of EFLOW object : $e^{\pm}$, γ and neutral hadrons vs charged hadron and their "noise"
- Threshold for low energy photon and distance cut to the closest charged hadron

Density, Granularity and Segmentation , Resolution

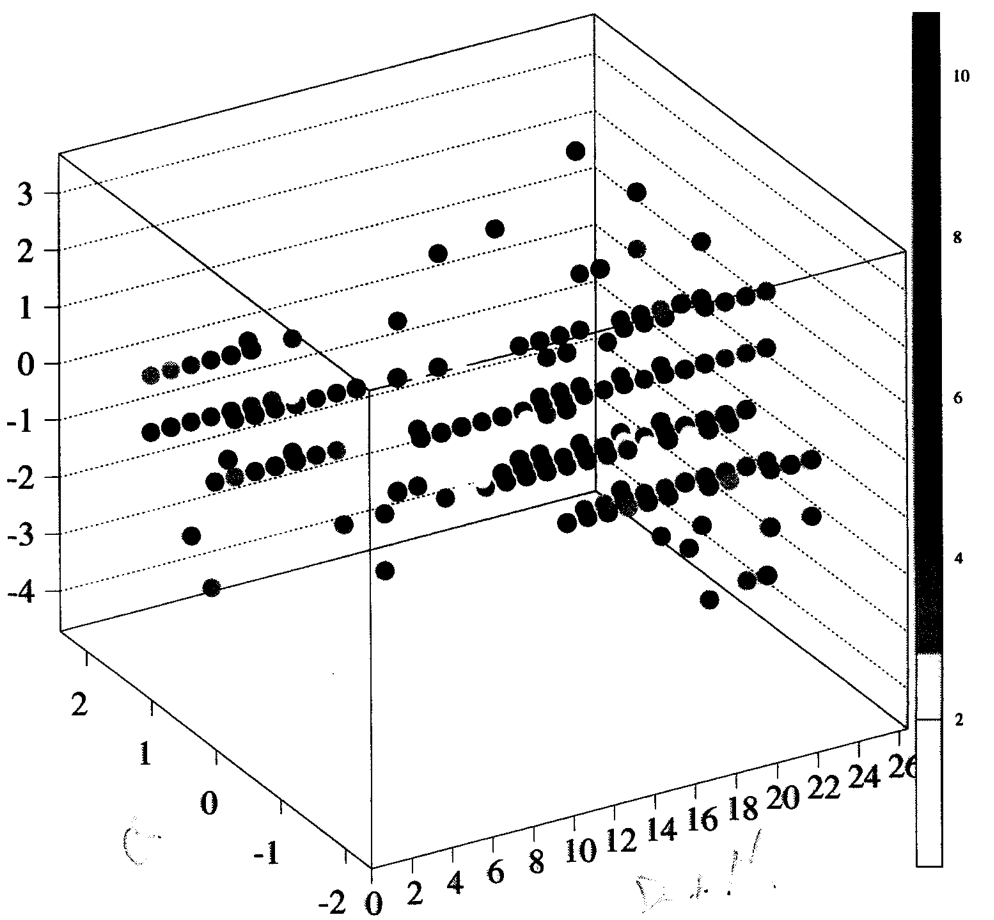
HCAL

- Resolution
- Reconstruction of EFLOW object : reconstruction of neutral hadron versus large hadronic shower coming from charged hadron

Tracking calor., Granularity and Segmentation , Resolution

10 GeV π^- at 1 cm from a 500 MeV photon

Geant-4 simulation



In 3-D calorimeter

Need a 3-D clustering algorithm

Which technic for a segmented calorimeter ?

ECAL	HCAL
Si-W	Si-Fe
Si-W	Scint.-Fe
Scint.-W	Scint.-Fe

BECAUSE

1 - Avoid Cu radiator in 3T B-field (discharge)

2 - Using Lead for ECAL has no mechanical and technical advantage but the cost is lower

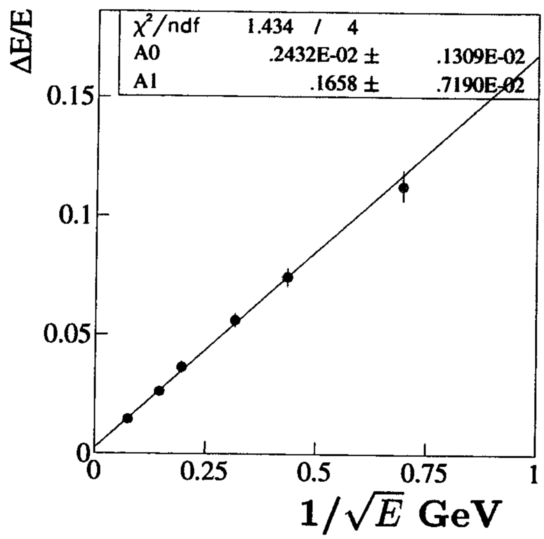
3 - The price of Si-MR (middle resistivity) has gone down in the past few years

- The geometry of a segmented calorimeter without too many dead regions is difficult
- In any case, number of channels is large
- For each choice there is a lot of problems to solve

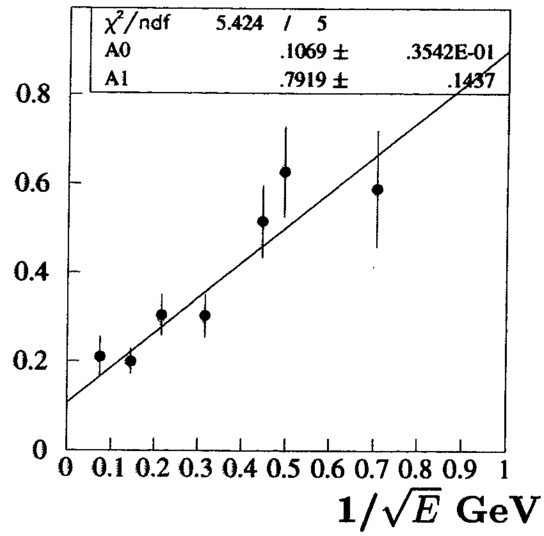
Geant-4 simulation Si-W

ECAL = 50 × (.18cm(W) + 300μm(Si) + 0.27cm(Air)) pad area 1×1 cm^2
HCAL = 20 × (2.cm (Fe) + 300μm(Si) + 0.27cm(Air)) pad area 1×1 cm^2

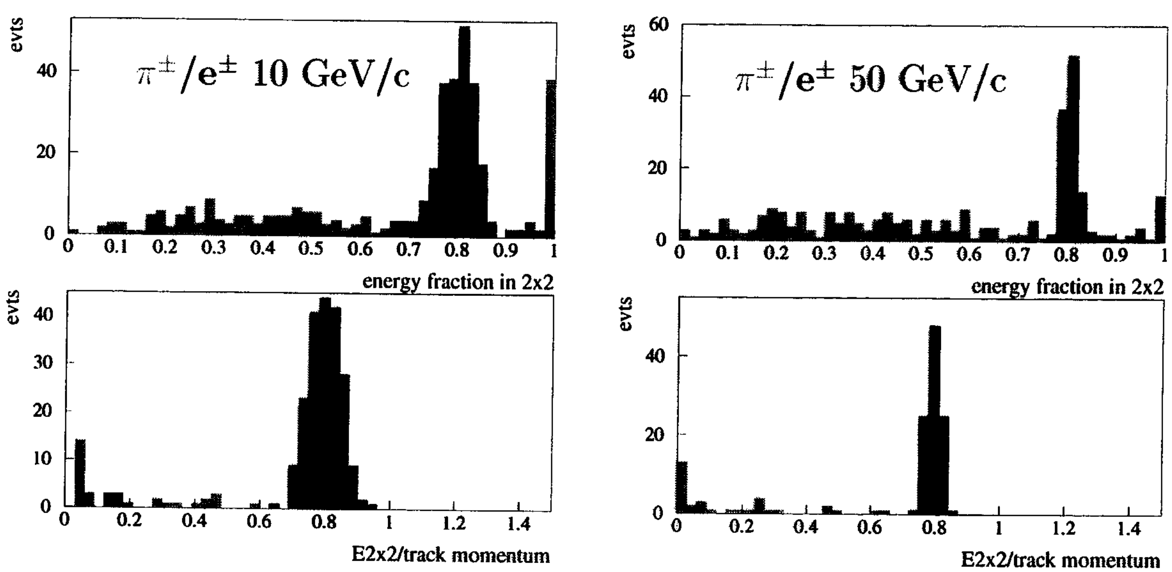
e$^\pm$/photon ECAL resolution



pion calorimetric resolution



electron Identification

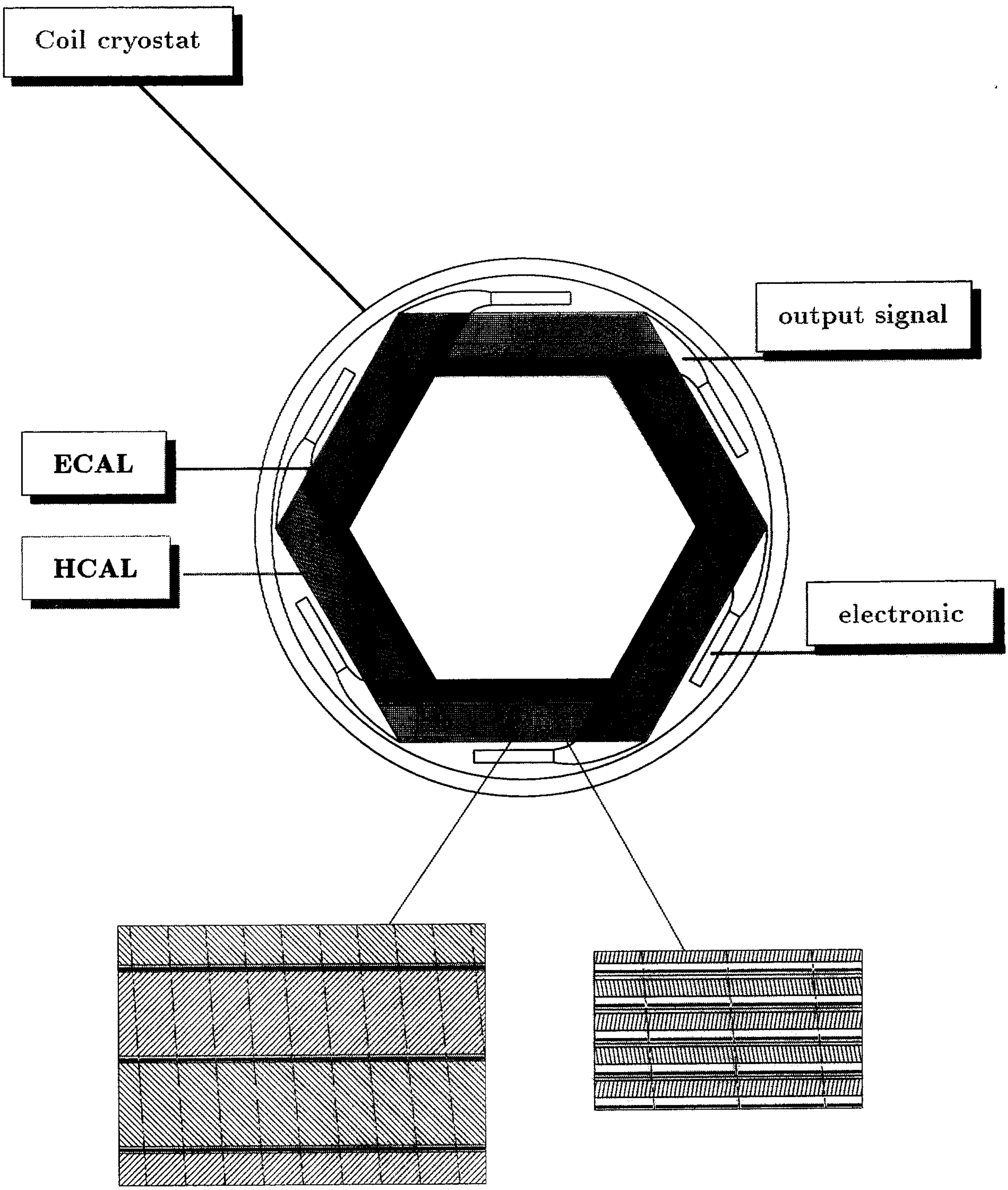


Keeping 100% of the electron, the rate of Misid. is very low

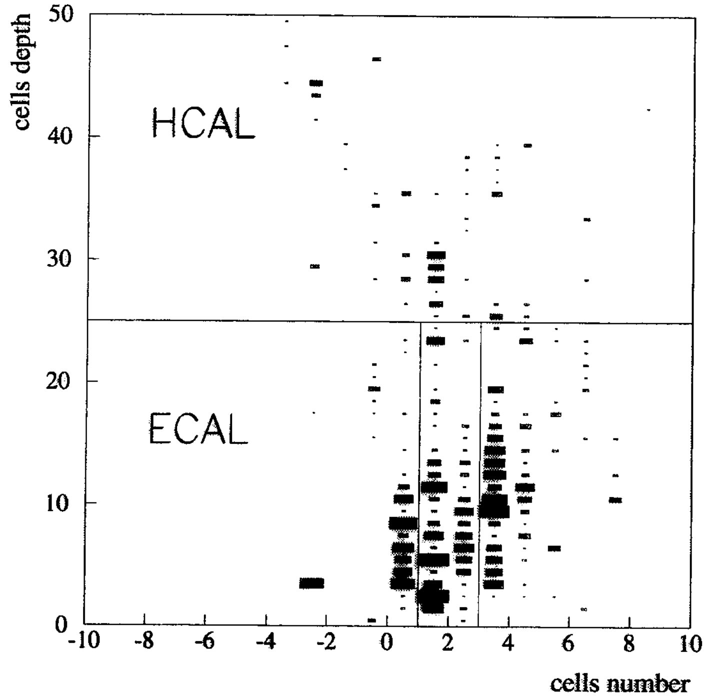
$\varepsilon(\pi \rightarrow e) < 6\ 10^{-3}$ (90% C.L.)

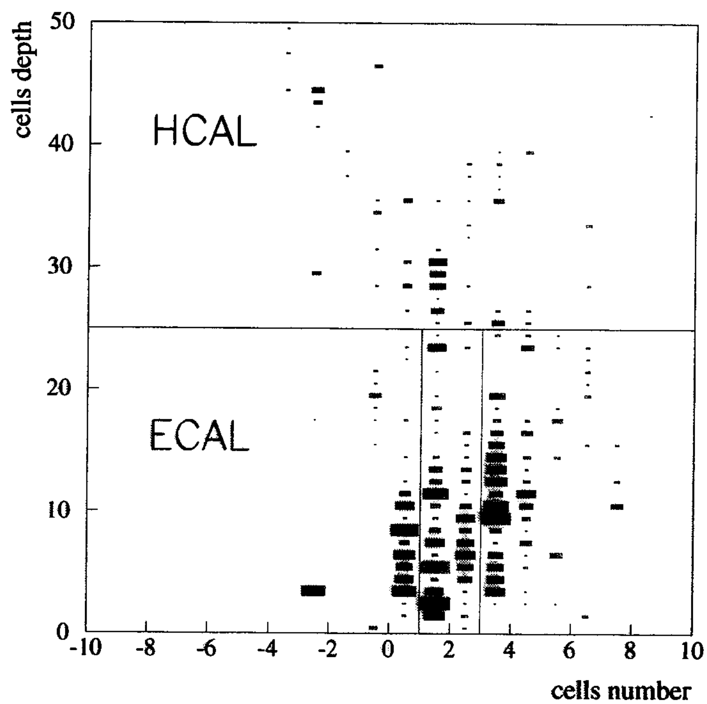
Isolated tracks, no Brem, no error on momentum

Example of geometry without cracks CALOR. BARREL - View XY



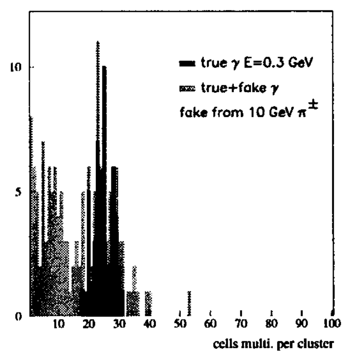
PHOTON + Charged PION .

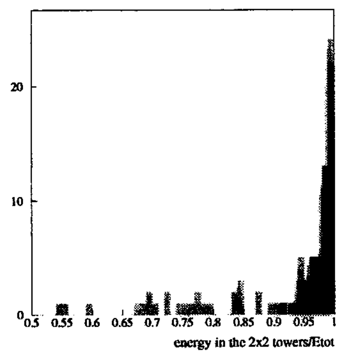


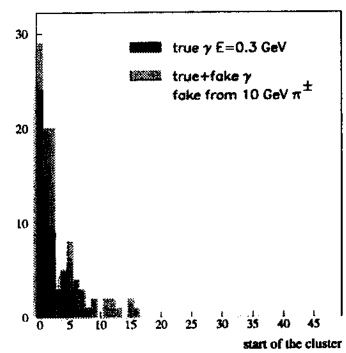


efficiency for low energy photon

With a specific clustering algorithm, the efficiency lies between 90% at 100MeV and 100% for $E\gamma = 0.3$, 0.5 and 1. GeV



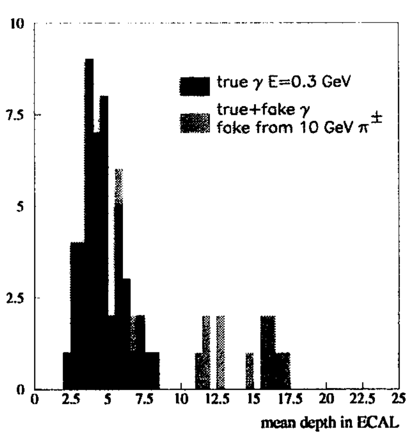


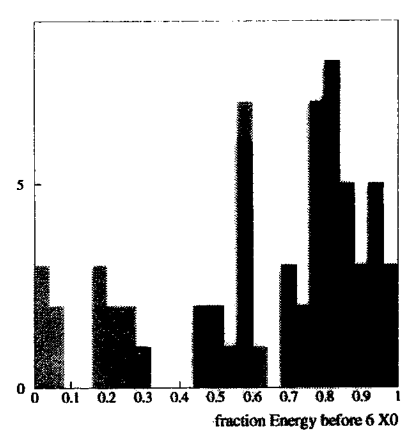


hadronic fake photon

Fraction of 10 GeV charged pion with at least 1 fake photon
10±3 % (ALEPH value is 15 ± 0.1) %

It could be improved (see plot)





Conclusion

A HIGHLY SEGMENTED CALORIMETER

is the best choice for EFLOW and physics with jets

- **excellent separation** e - μ - π - γ - K^0_L,n
- **3D clustering**

  → reconstruct low E photon at dist.$\geq$ 1-2 cm

  → reconstruct neutral hadron at dist.$\geq$ 2-4 cm

(clearly dependant of Eh and momentum of the closest charged)

  → good rejection of hadronic fake photon

- **direction of calorimetric object**

(noise reduction, interest for specific physics channels)

- **the resolution** , estimated from Geant, is about $0.15/\sqrt{E}$