Energy Flow

with high granularity calorimeters

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OUTLINE

- Introduction
- Concepts
- Status of the art
- Prospects
- Conclusion

INTRODUCTION

Which Final states are under consideration ?

$Z\gamma$	**2 ℓ, 2 jets**
W^+W^-	**1 ℓ+2 jets, 4 jets**
$t\bar{t}$	**ℓ+jets, 6 jets**
$t\bar{t}h$	**8 jets**
hZ	**2ℓ+2 jets, 4 jets**
hhZ	**2ℓ+4 jets, 8 jets**
$\chi_1^\circ\chi_1^\circ$	**jets + $\not{E}$**
$\tilde{t}\bar{\tilde{t}}$	**6 jets+$\not{E}$**
$\not{R}_p$ $\chi_1^\circ\chi_1^\circ$	**2ℓ+ 4 jets, 6 jets**
$\not{R}_p$ $\chi^+\chi^-$	**2ℓ+ 6 jets, 10 jets**
graviton	**no-pointing γ**
extra-dimension	**γ+$\not{E}$**

Jets Physics is of major importance

requests:

- **jet reconstruction**
- **Good tagging of b, c quarks and τ lepton**
- **Lepton/hadron identifications;** $e^\pm, \mu^\pm, \mathrm{hadron}^\pm$

INPUTS (1)

Inputs from Physics

multijets final state	$\Rrightarrow$	jet reconstruction
missing energy resolution	$\Rrightarrow$	hermicity
b, c quarks and τ tagging	$\Rrightarrow$	lepton Id. + jet reconstruction

Inputs from the machine

machine background leads
to a 3-4 T field

coil thickness is $\sim 2\ \lambda_{\mathrm{I}}$	$\Rrightarrow$	ECAL, HCAL inside coil
	$\Rrightarrow$	compactness
	$\Rrightarrow$	μ Id. in calorimeter (P$<$5-8GeV/c)

jet reconstruction requires other inputs

INPUTS (2)

Inputs from jet reconstruction

or how to design the calorimeters ?

- **Energy and angular resolution have to be excellent (*e.g.* $\Delta E_\gamma / E_\gamma \sim 10\% / \sqrt{E_\gamma}$)**
  But not only ...

For example (from an exp. as ALEPH)

• @$\sqrt{s}$=91 GeV, resolution on visible mass ΔM_{vis}=	6.5GeV
calorimeter energy resolution	$\sim$ 3.0 GeV
imperfect particle reconstruction	$\sim$ 5.5 GeV

- **Due to increase of dead zone of ECAL, resolution behaves as $\Delta M_{vis} \times (1 + \|\cos\theta\|)$**

requierements from jet reconstruction

$\Rrightarrow$ **Calorimeters optimized for the reconstruction (not for the resolution only)**

$\Rrightarrow$ **calorimeters w/o cracks both in Barrel and End-caps**

$\Rrightarrow$ **uniformity**

INPUTS (SUMMARY)

hermiticity **(no cracks, full coverage)** **uniformity** **compactness**	$\Rrightarrow$	**dedicated geometry** **instrumented mask**
identification of e/μ/$h^{\pm}$	$\Rrightarrow$	**s/b at mip level**
cal. optimized for resolution	$\Rrightarrow$	**small pad size** **high granularity**

how to test the different designs ?
In contrast w/ the usual tests performed w/ single particles ($e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$), tests have to be performed through an EFLOW algorithm for the point of view of jets.

$\Rrightarrow$ **EFLOW is part of the detector design**

Framework

consists in ECAL and HCAL design and Jet reconstruction algorithm

- **detectors**

ECAL Si/W sampling calorimeter

Known principle

all requests fulfilled

$\Delta E_\gamma / E_\gamma \sim$ 10.3%/$\sqrt{E_\gamma}$

1x1cm^2 pad size

HCAL Digital calorimeter

sampling calorimeter (inox) with digital pad read-out

energy reconstructed from pad multiplicity (principle tested w/ ALEPH data)

1x1cm^2 pad size

- **EFLOW algorithm**

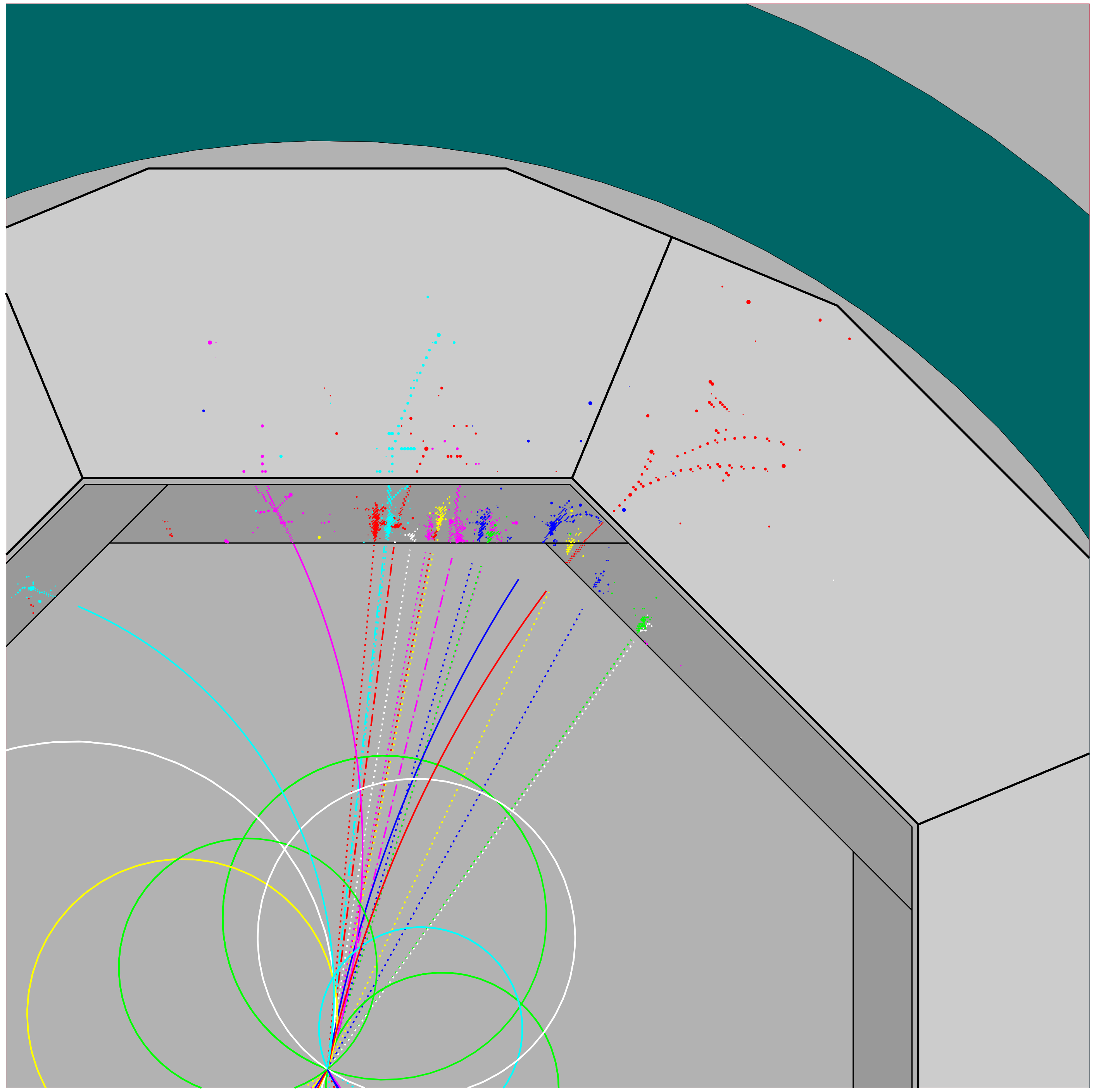
$$E_{jet} = \Sigma\ E_{ch} + \Sigma\ E_\gamma + \Sigma\ E_{neutralh}$$

Identification and reconstruction of all eflow objects

- Charged tracks from tracker system
- Photons from ECAL $\Rrightarrow$ photon reconstruction★
- Neutral hadrons (K_L, neutron) from ECAL & HCAL $\Rrightarrow$ neutral hadron reconstruction★

★ w/ rejection of debris from charged hadron interaction

GRANULARITY



Zoom on the transverse view of the detector

Visualization performed w/ `FANAL` package developed by H.Videau

Photon reconstruction	
	classical clustering algorithm
Lepton Identification	
	classical technique based on likelihood estimator
Neutral hadron reconstruction	
	software of image processing for digital calorimeter - topological approach

⇛ **Jet reconstruction**

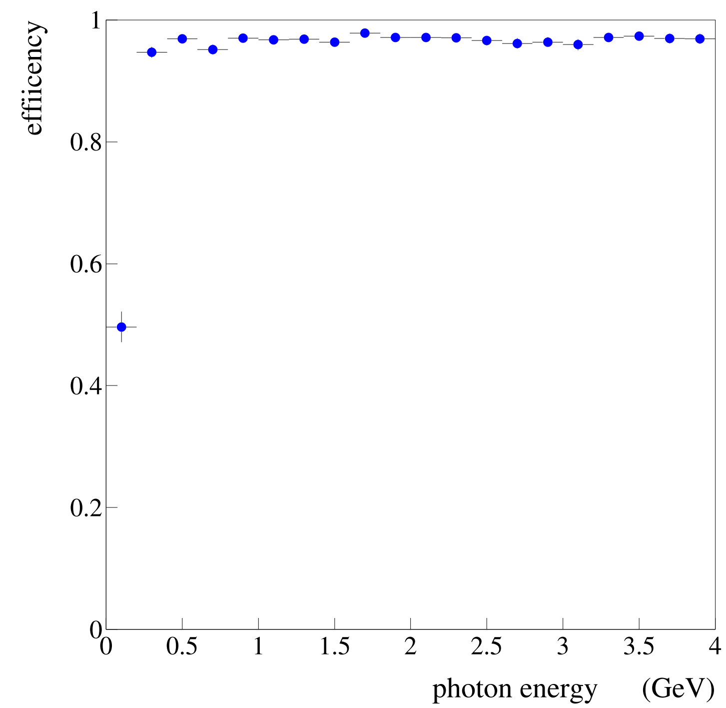
Refs
[Talks ECFA-DESY Workshop in Obernai]
[Talks ECFA-DESY Workshop in Padova]
[LC-note in preparation]

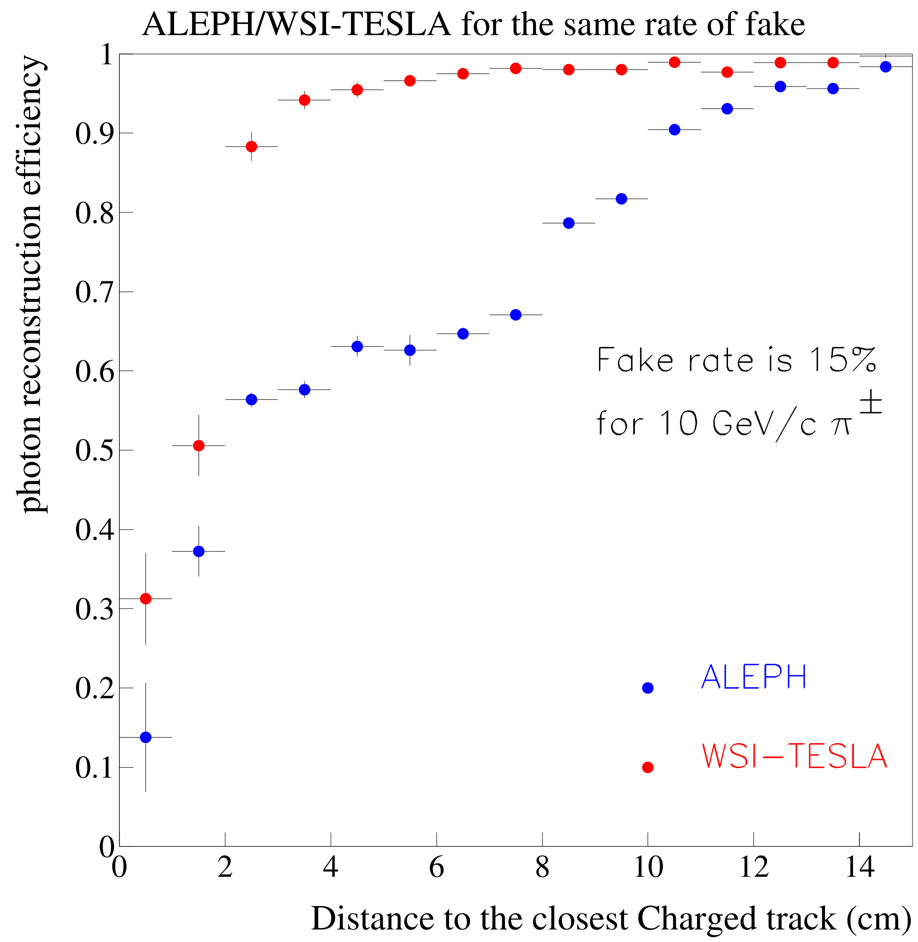
in more details ...

Photons

Anyway some benchmarks are needed

PFD efficency to find photon in the low energy region
$\sim$ 99% above 0.25 GeV





Photon reconstruction efficiency as a function of the distance to charged tracks ($\pi^{\pm}$)

Eff. greater than 85% since 3 cm and 50% at 2 cm

(for a fake rate $\sim$ 15%)

Largely better than ALEPH

up to 10 cm

Lepton Id

- **Isolated tracks**

ID/particle	$e^{\pm}$	$\mu^{\pm}$	$h^{\pm}$
$e^{\pm(1)}$	**99.8%**	**0.**	$\sim$**5.**10^{-4}
$\mu^{\pm(2)}$	**0.**	**99.8%**	$\sim$**5.**10^{-3}
$h^{\pm}$	**0.2**	**0.2%**	**99.5%**

(1) *Refs. cf LC-note on Eflow in preparation*
(2) *Refs. cf talk in ECFA-Obernai*

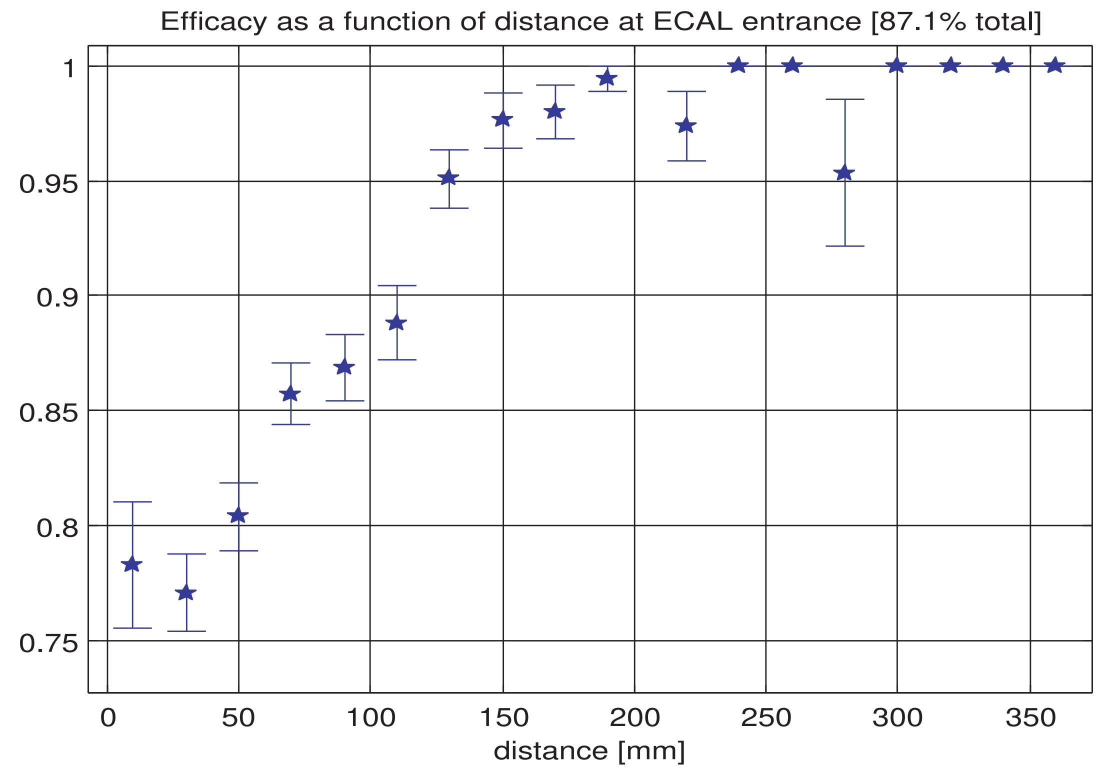
- **In jet**

ID/particle	$e^{\pm}$	$\mu^{\pm}$	$h^{\pm}$
$e^{\pm(3)}$	-	-	-
$\mu^{\pm(4)}$	**0.**	**92%**	$\sim$**1.5**10^{-2}
$h^{\pm}$	-	**8.%**	-

(3) *not yet ready*
(4) *including low P_t down to 2 GeV/c*

Neutral hadrons

Reconstruct a neutral hadron very close to a charged track is possible
with a reasonable efficiency : $\sim$75% @ 1 cm



Full simulation and reconstruction

no use of $\pi^{\pm}$momentum

code not yet adapted for jets (very slow)

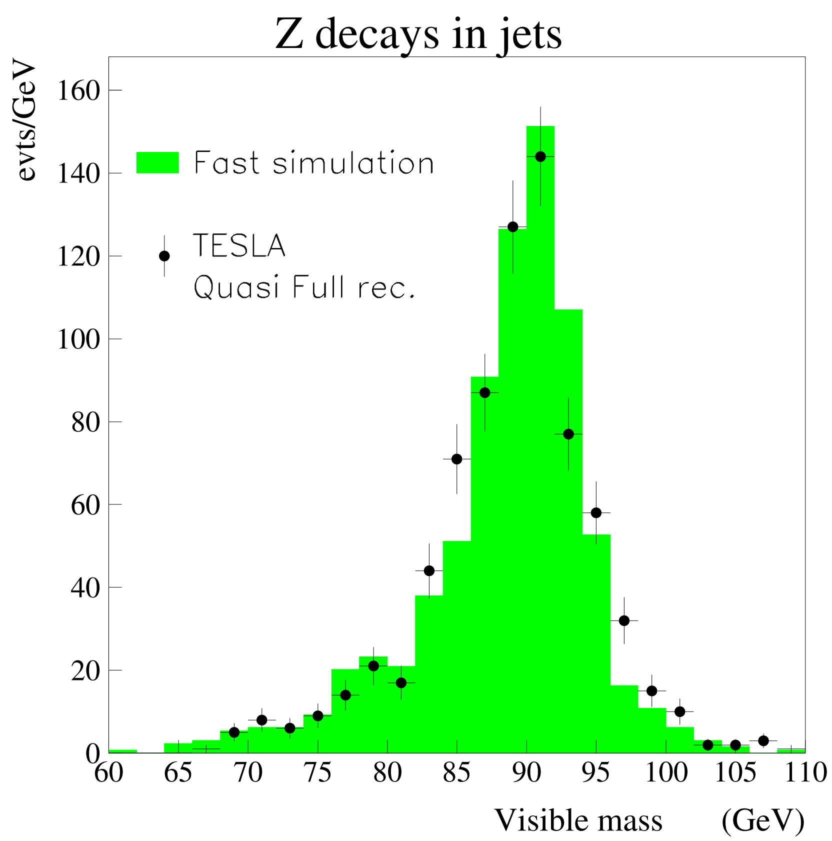
thus a fast simulation based on output from full reconstruction has been used for jets

JETS (1)

Quasi-full reconstruction

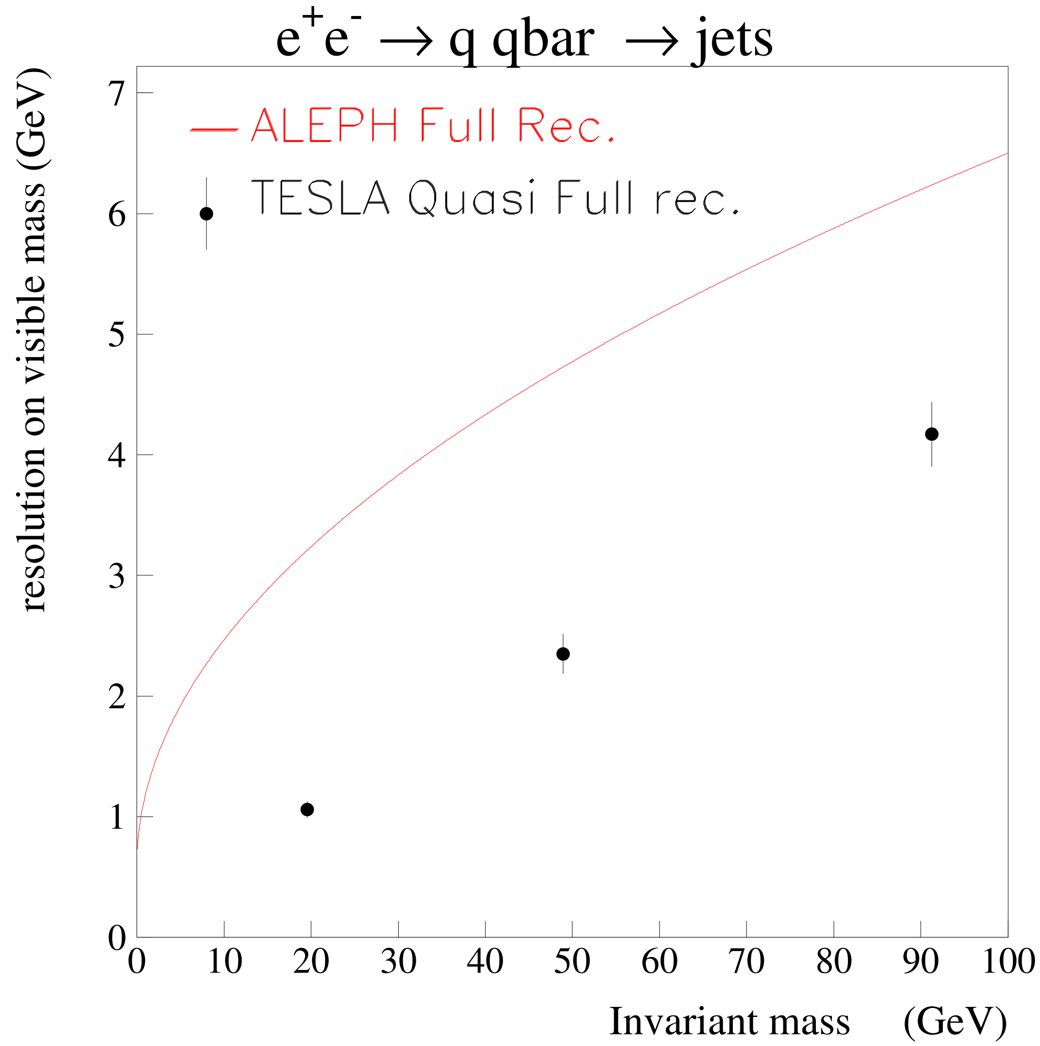
- **Charged tracks**
  fast simulation
  $\mathcal{E}_{\mathrm{track}}$**=99.7%**
  $\mathrm{P}_{\mathrm{min}}$**=0.2GeV/**$\mathrm{c}^2$
- **Photons**
  full reconstruction
  $\mathrm{E}_{\mathrm{min}}$**=200 MeV**
  no calibration
- **Neutral hadrons (**$\mathrm{K_L}$**, neutrons)**
  fast simulation
  fake rate and $\mathcal{E}(\mathrm{E},\mathrm{dist})$ **from full reconstruction**
  $\mathrm{E}_{\mathrm{min}}$**=500 MeV**

Test



Jets (2)

Gain in resolution for jets final state and comparison with ALEPH for instance



clear improvement is obtained @ 91 GeV $\Delta M_{vis} \sim$4.2 GeV

the point @ 91 GeV has been tested with the full reconstruction $\Delta M_{vis} \sim$4.2 GeV has been found; confirming the result of quasi-full reconstruction

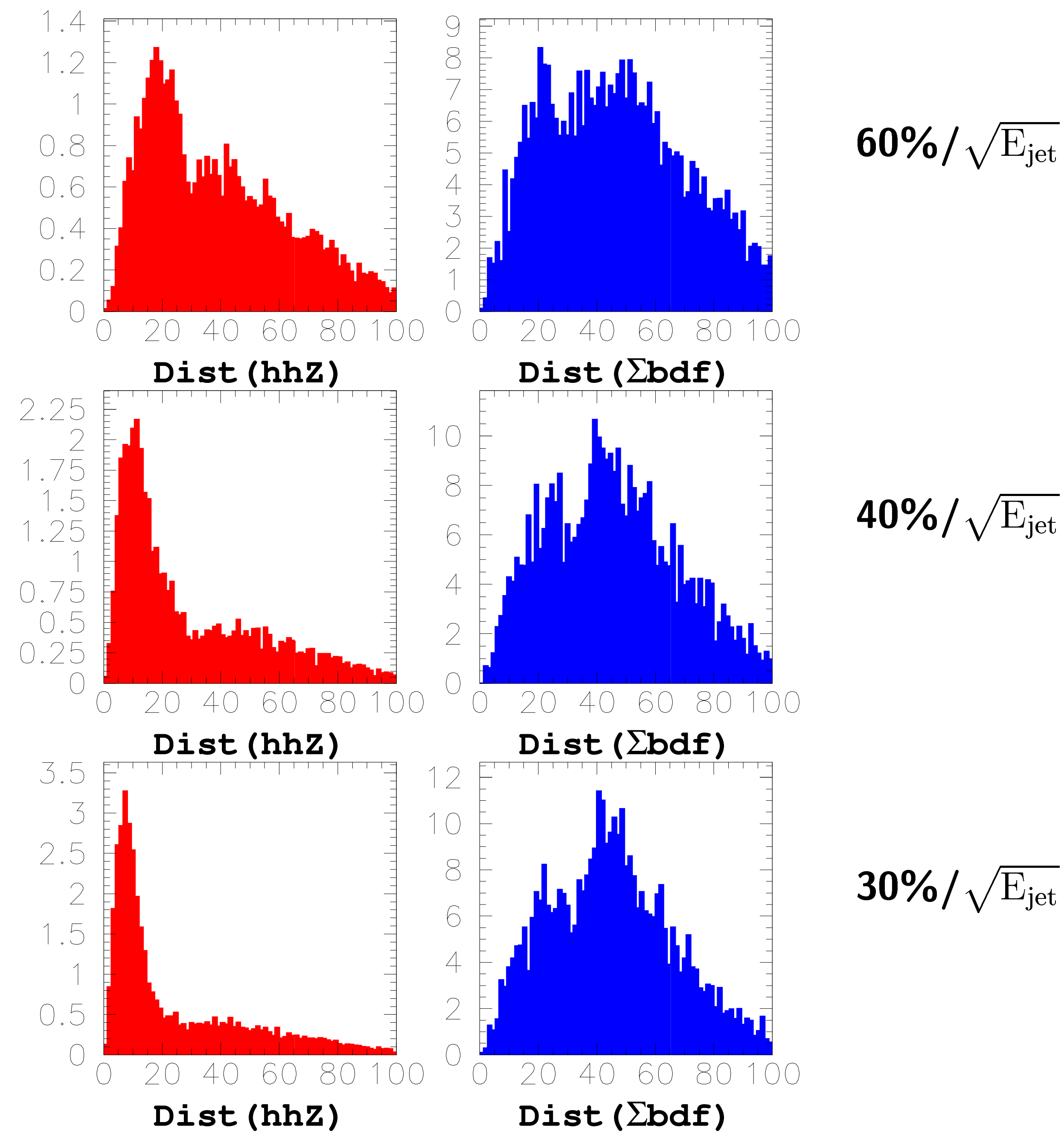
Impact on analysis ?

ILLUSTRATION

As an illustration $e^+e^- \to hhZ \to$ **6 jets**

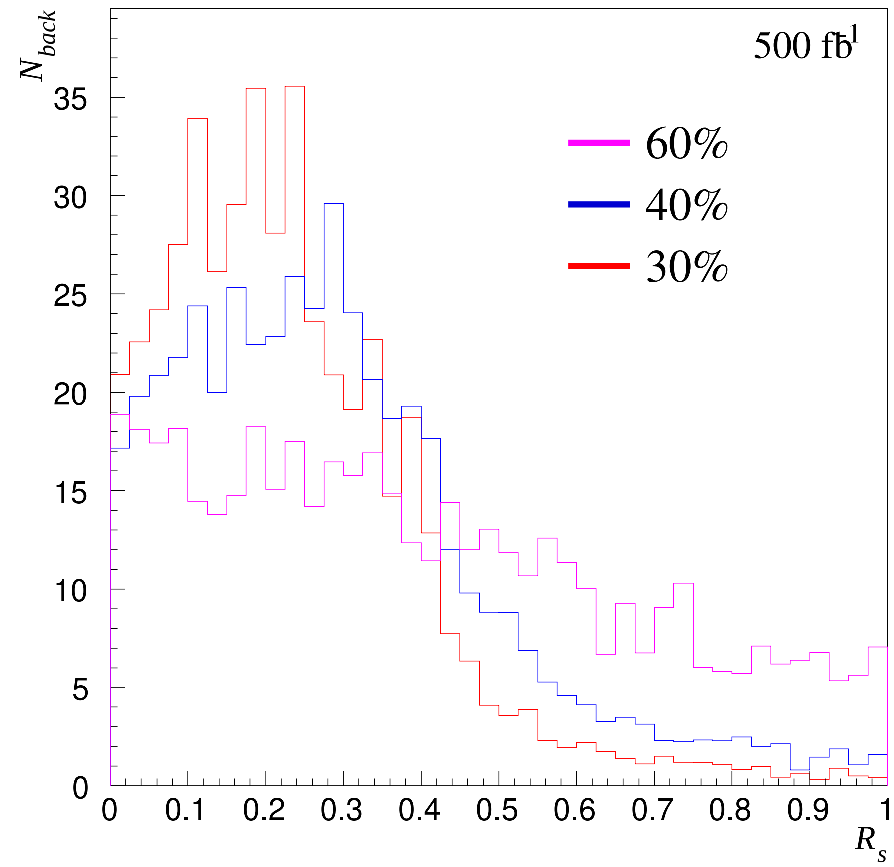
(test of the Higgs potential, measurement of the trilinear Higgs coupling λ_{hhh})

- **3 di-jets masses are simply combined to form the** *distance*
  Dist=$\sqrt{((m_{12}-120)^2+(m_{34}-120)^2+(m_{56}-m_Z)^2)}$



Illustration

Background distributions Expressed in term of rarity wrt signal distribution



Background level @ $R_s > .5$ (ϵ_{hhz}=50%) $\mathcal{L}$=500fb^{-1}

$\Delta E_{jet}/E_{jet}$	60%$/\sqrt{E_{jet}}$	40%$/\sqrt{E_{jet}}$	30%$/\sqrt{E_{jet}}$
N_{back}	**160.2**	**62.2**	**28.**

background level is reduced by a factor $\sim$ 6

impact on λ_{hhh} measurement (2000fb^{-1})

$\Delta E_{jet}/E_{jet}$	60%$(1+\|\cos_{\theta_j}\|)/\sqrt{E_{jet}}$	60%$/\sqrt{E_{jet}}$	40%$/\sqrt{E_{jet}}$	30%$/\sqrt{E_{jet}}$
$\Delta\lambda_{hhh}/\lambda_{hhh}$	**36%**	**32%**	**26%**	**22%**

EFLOW w/ $\sim$40%$/\sqrt{E_{jet}}$ is a powerfull (and mandatory) tool in multijets analysis

PROSPECTS

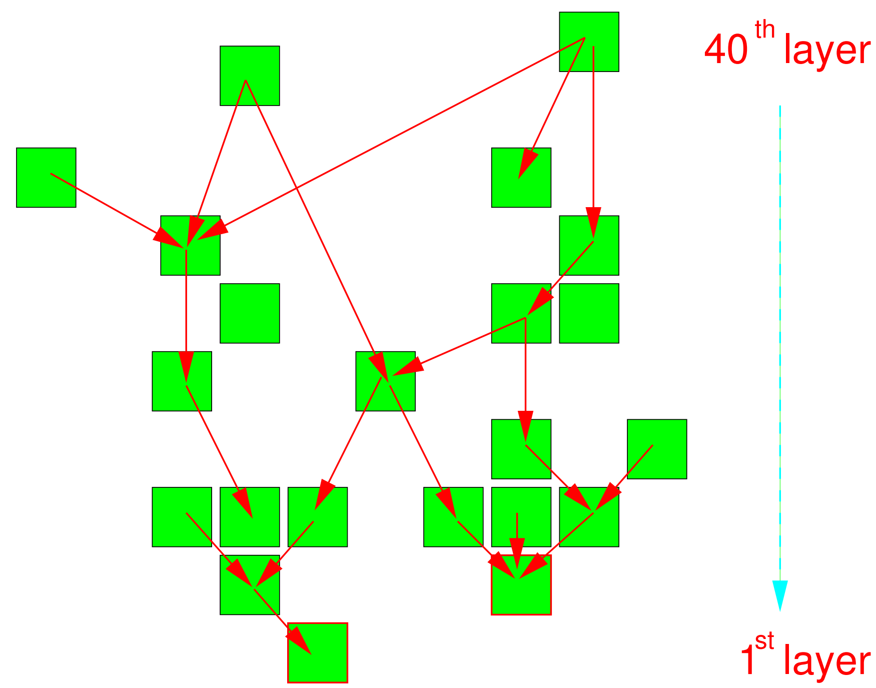
Is that the Ultimate Point ? No

Besides the Standard approaches new ones are in development :

Energy Measurement Intended for Low Em showers

statistical approach

- **3D**
- **Long range**

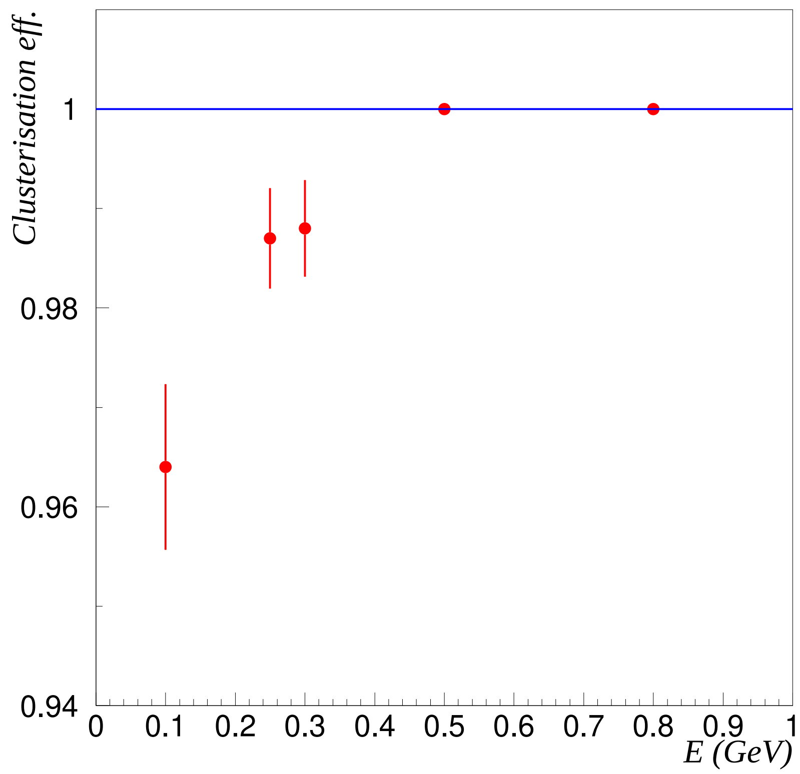


at each terminal pad an object ('cluster') is connected

- **link between two pads as a function of the energy deposited and the distance**
- **every pad are connected w/o any initiate pad**
- **the energy from a pad could be shared by many objects**

Energy Measurement Intended for Low Em showers

with photon from 100 MeV up to 1 GeV



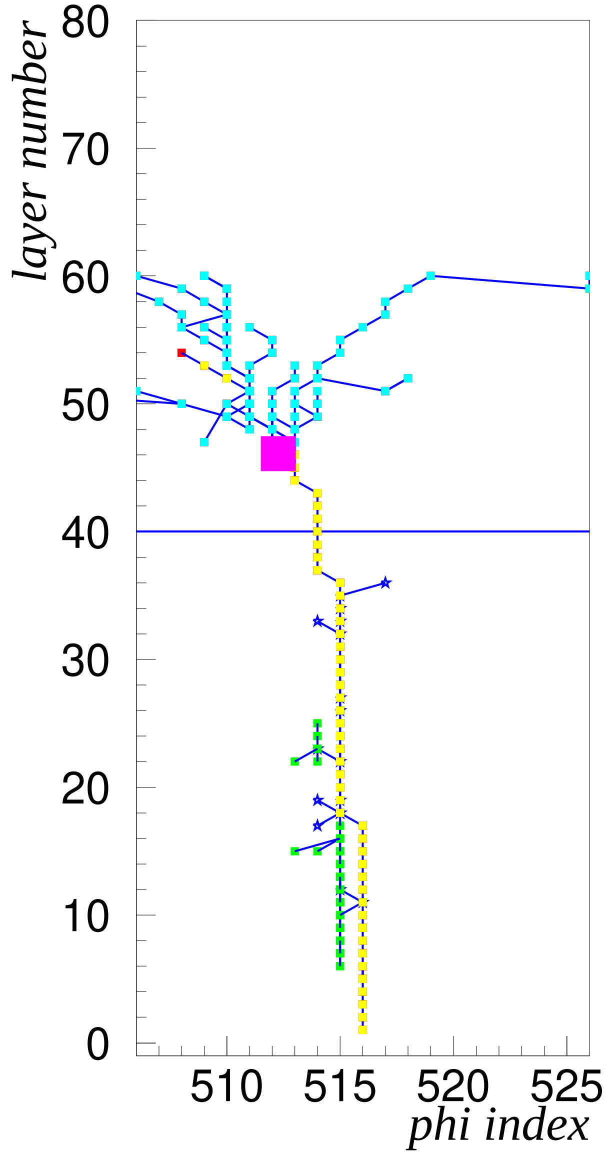
clusterisation efficiency is $\sim$96% @ 100 MeV and a resolution $\sim$35 MeV

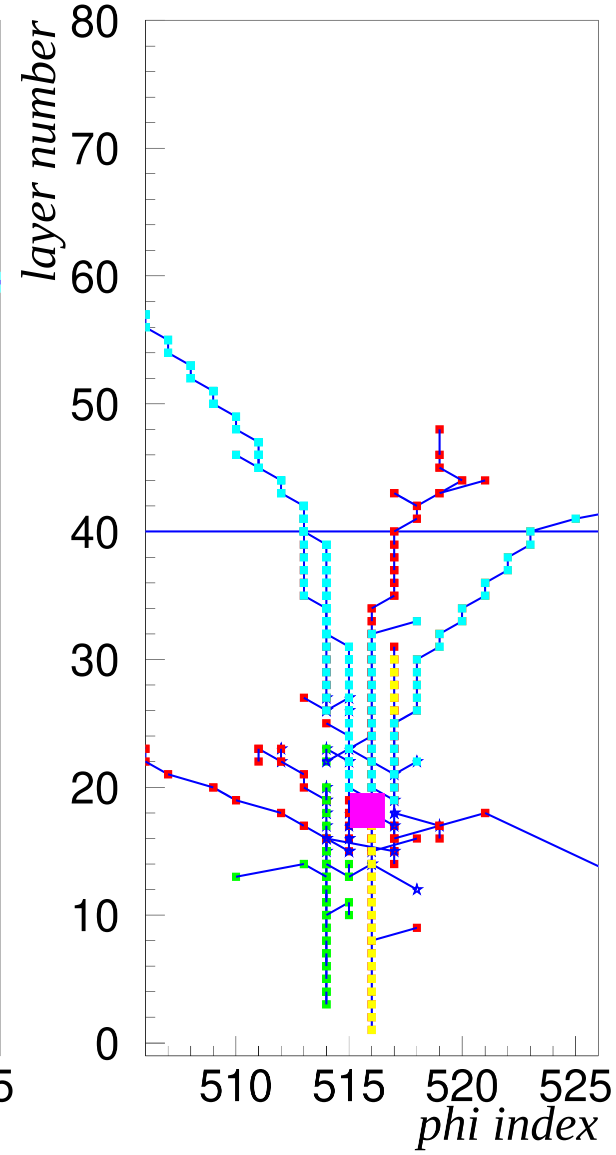
PROSPECTS

Photons with $\pi^{\pm}$

high granularity $\Rrightarrow$ pattern recognition
only use geometry informations;

- **define the branches**
- **vertexing (vertex of the hadron)**
- **remove branches from the vertex**
- **branch which match entry point of charged track is $\pi^{\pm}$**
- **use EMILE on the remaining pads**
- **distance between CoG of EMILE objects and Vertex position is used to eliminate the fake photons**

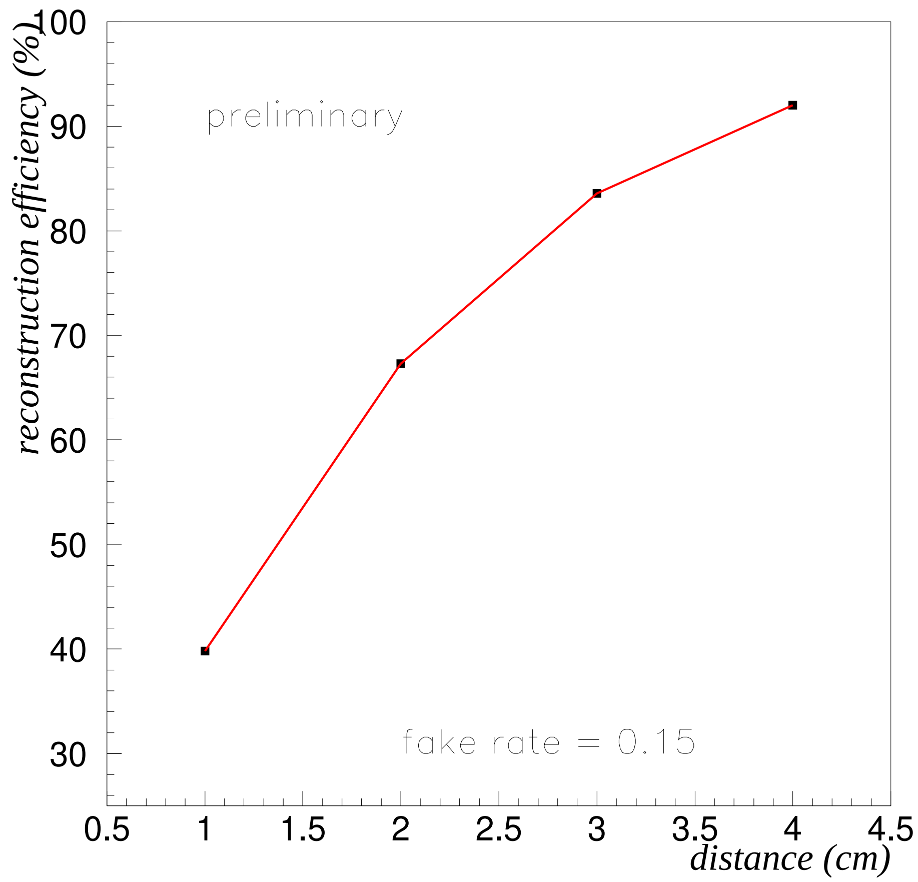




PROSPECTS

with a crude vertexing method and branch definition for γ(1GeV)/$\pi^{\pm}$(10GeV)

eff.$_{\gamma}$ as a function of the distance



potential gain

NB.

ΔM_{vis}	e.m.	neutral h	$h^{\pm}$
4.2 GeV/c^2	1.7 GeV/c^2	3.9 GeV/c^2	-

'vertex' reconstruction in ECAL/HCAL would be a solution to improve the K/$\pi^{\pm}$separation

Prospects

with a crude vertexing method and branch definition for γ(1GeV)/$\pi^{\pm}$(10GeV)

eff.$_{\gamma}$ as a function of the distance

distance	1 cm	2 cm	3 cm
$\epsilon_{\mathrm{recons}}$	40%	67%	84%

NB.

$\Delta \mathrm{M}_{\mathrm{vis}}$	e.m.	neutral h	$h^{\pm}$
4.2 GeV/c^2	1.7 GeV/c^2	3.9 GeV/c^2	-

'vertex' reconstruction in ECAL/HCAL would be a solution to improve the K/$\pi^{\pm}$separation

CONCLUSIONS

- **Multi-jets is of major importance for the next LC-Physics**

- **Beside intrinsic performances of the sub-detectors,**
  - **the calorimeters have to be designed in their whole and throught the EFLOW algorithm**
  - **EFLOW performances is the test of the detector design**

- **With high granularity calorimeters (Si/W ECAL & Digital HCAL)**

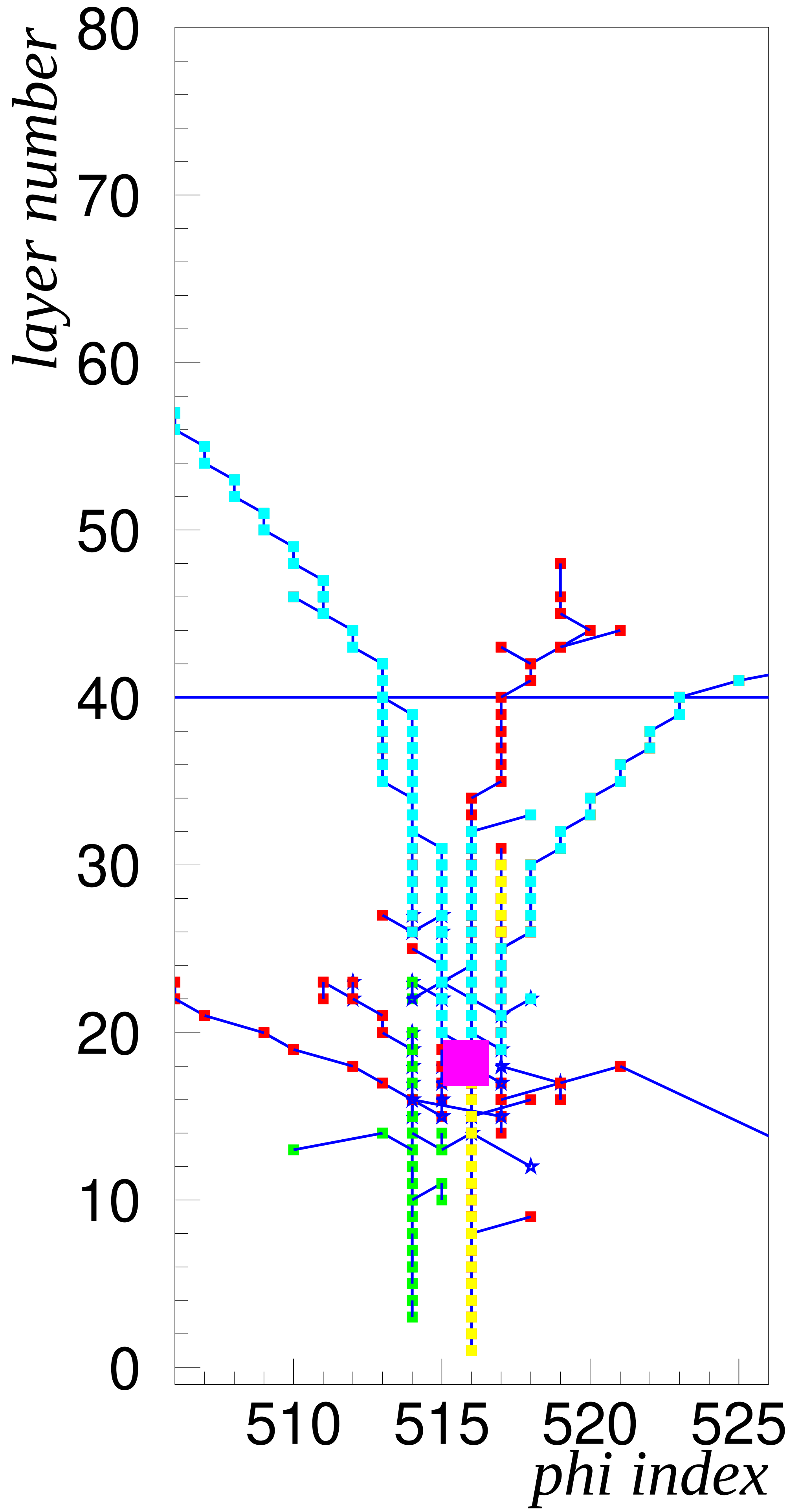
  $\Delta E_{jet}/E_{jet} \sim$ **40%**$/\sqrt{E_{jet}}$ **is achievable**
  (full simulation/reconstruction in calos)

- **Alternative ideas (statistical and pattern treatment) open the path leading to better performances**

  ($\Delta E_{jet}/E_{jet} \sim$ **30%**$/\sqrt{E_{jet}}$**?)**

http://polywww.in2p3.fr/tesla/ecal english.html
http://lc-ecal.in2p3.fr/

Photons with $\pi^{\pm}$



Photons with $\pi^{\pm}$