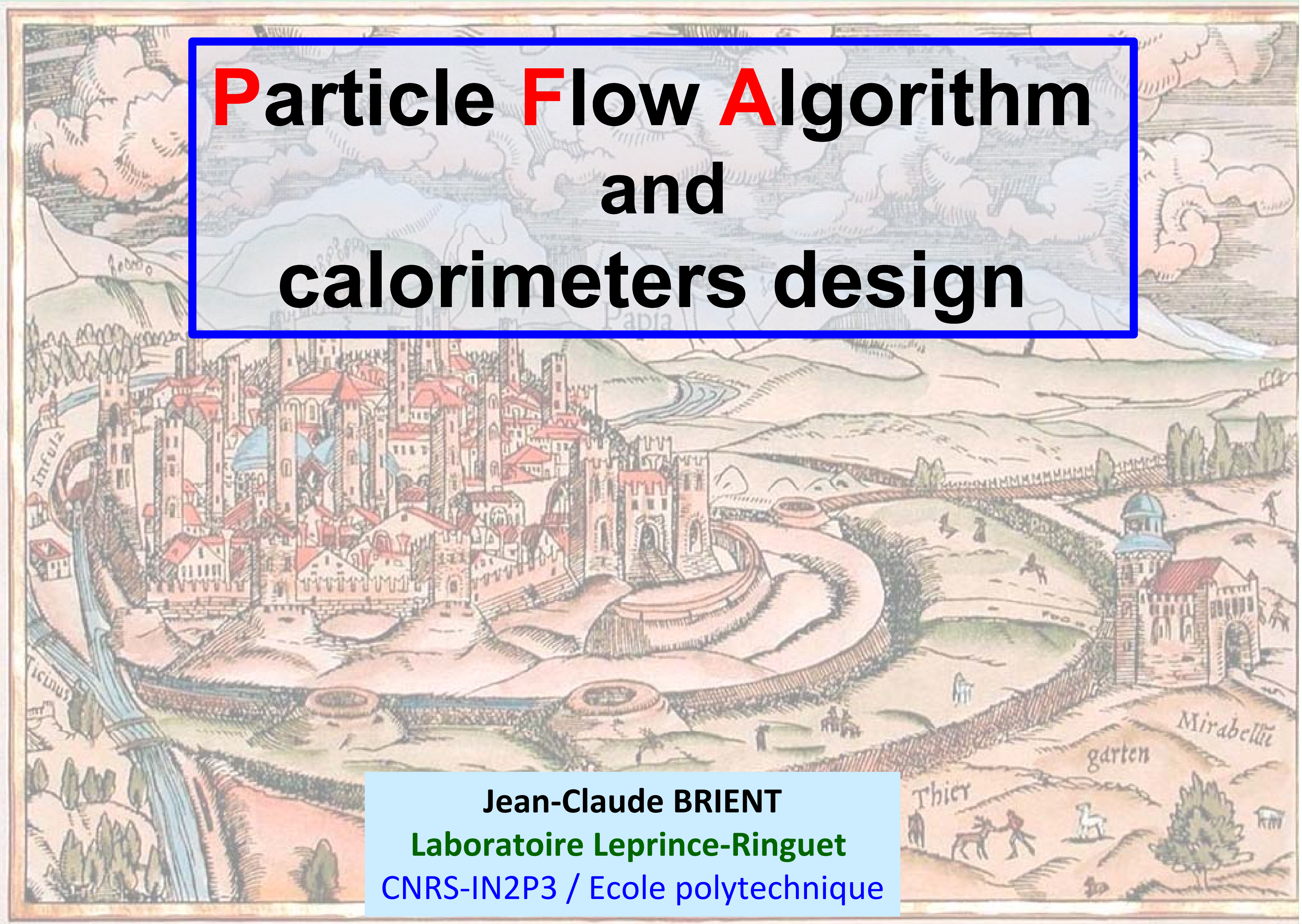

Particle Flow Algorithm and calorimeters design

Jean-Claude BRIENT
Laboratoire Leprince-Ringuet
CNRS-IN2P3 / Ecole polytechnique

Start from physics @ILC,CLIC, Not from a technology …

e+e- interaction 0.09 – 1.0 TeV

The main interesting processes (out of possible SUSY)

Multi bosons	Multifermions + Boson(s)
ZH	e^+e^- H , e+e− Z
WW	νν H , νν Z
ZZ	ttH
ZHH	e ν W
ZZZ	νν WW, νν ZZ
ZWW	ttbar in bbar WW

Etc … but also the taus decays reconstruction for SUSY, CP… etc

Start from physics @ILC,CLIC, Not from a technology …

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Need Boson Tagging

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ZZZ	νν WW, νν ZZ
ZWW	ttbar in bbar WW

Etc … but also the taus decays reconstruction for SUSY, CP… etc

Best use of the luminosity … use the decays in jets

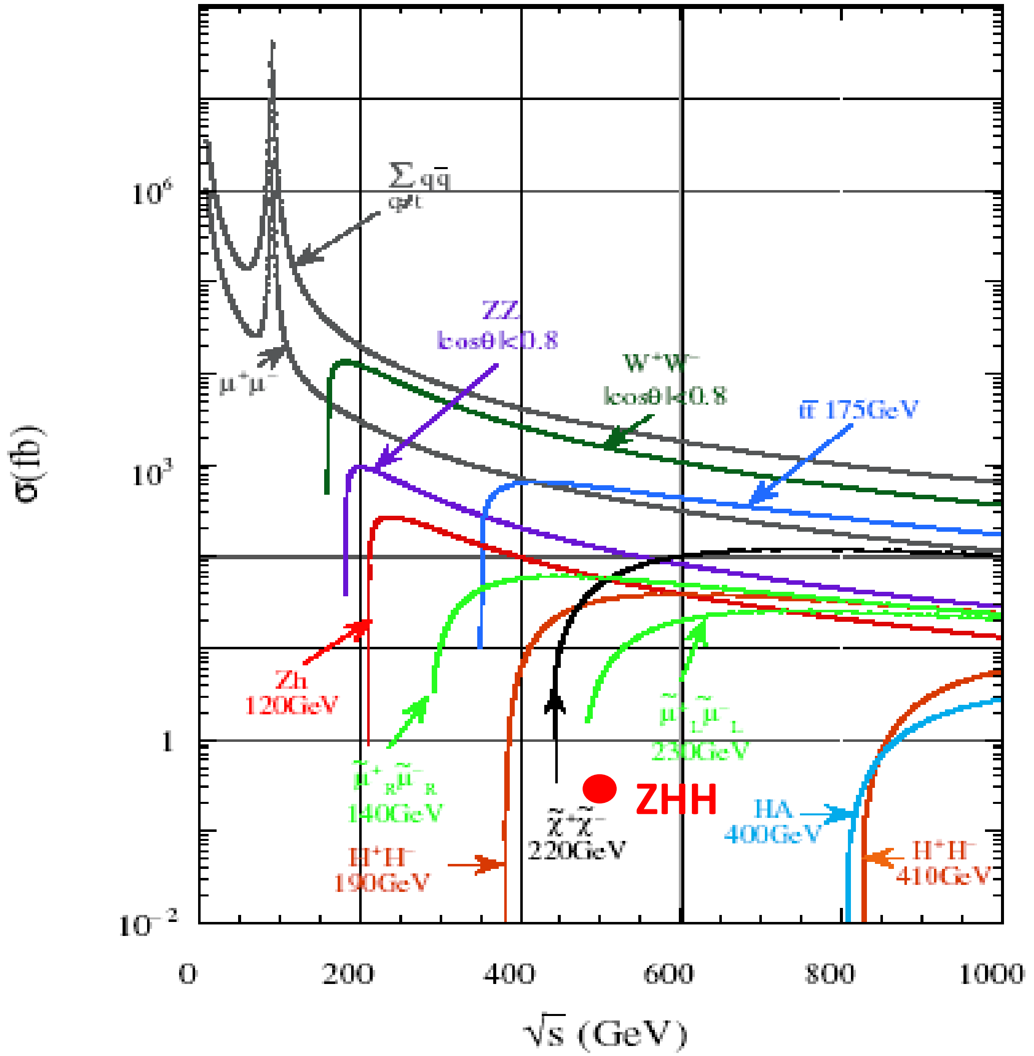
Z to	BR
$\ell^+ \ell^-$	10%
qq (jets)	70%

W to	BR
$\ell^\pm \nu$	32%
qq' (jets)	68%

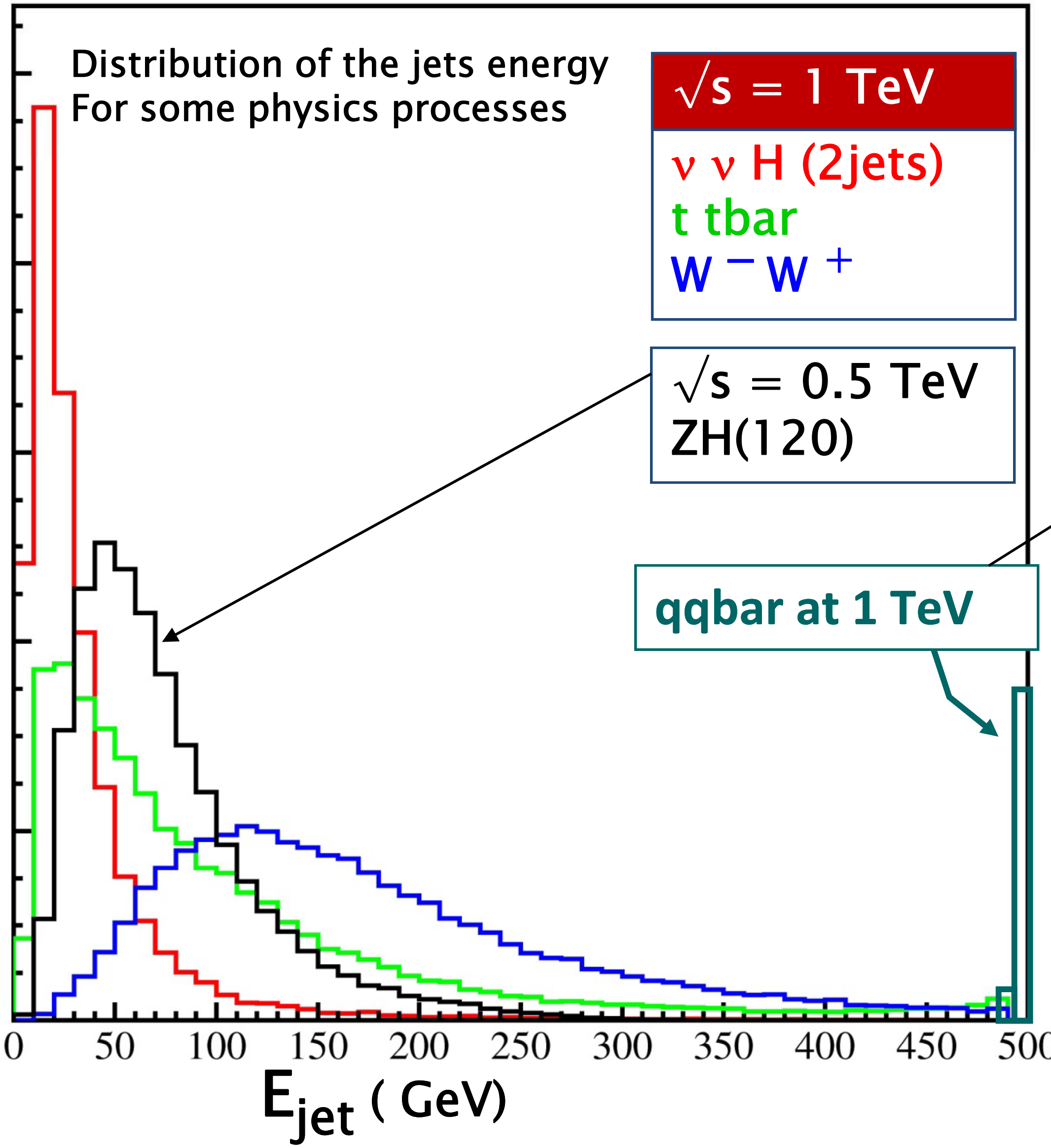
H(120,SM) to	BR
$\ell^+ \ell^-$	<15%
qq(jets) ,WW,ZZ	>85%

Is it possible at ILC,CLIC ?

Possible because S/B in jets final state is good enough on e^+e^- machine



Jet energy range of interest



But which physics needs a good Jet energy resolution for this process ?

Needs to be good up to 250-300GeV

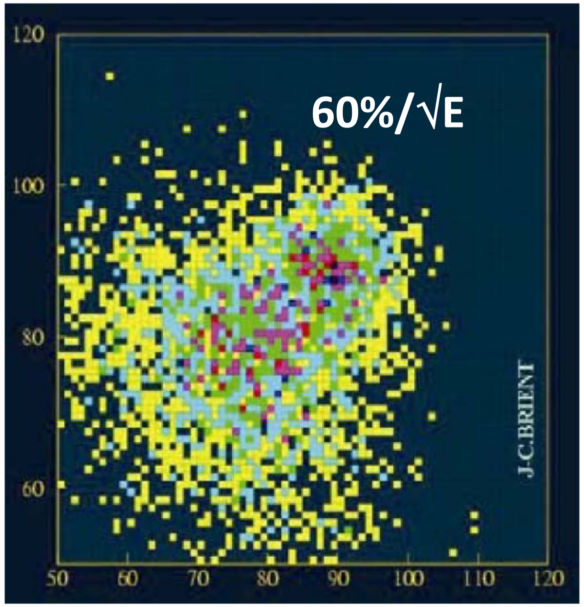
Boson Tagging

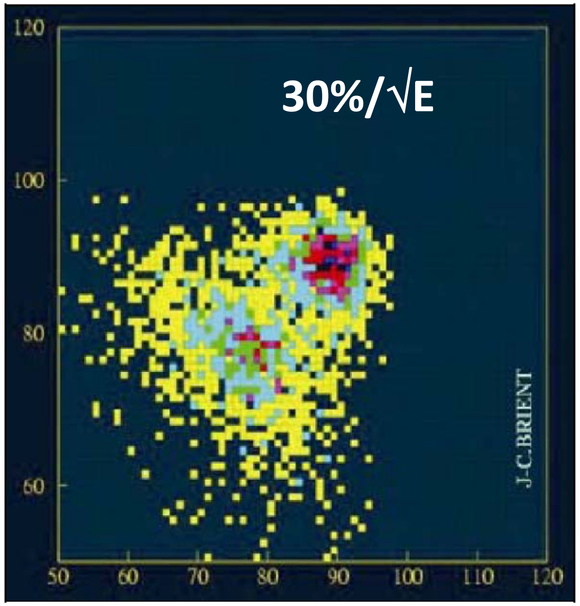
HOW MUCH GOOD ?

Tagging improves as long as we have $\sigma_{(dijetmass)} < \Gamma^{tot}_{boson}$

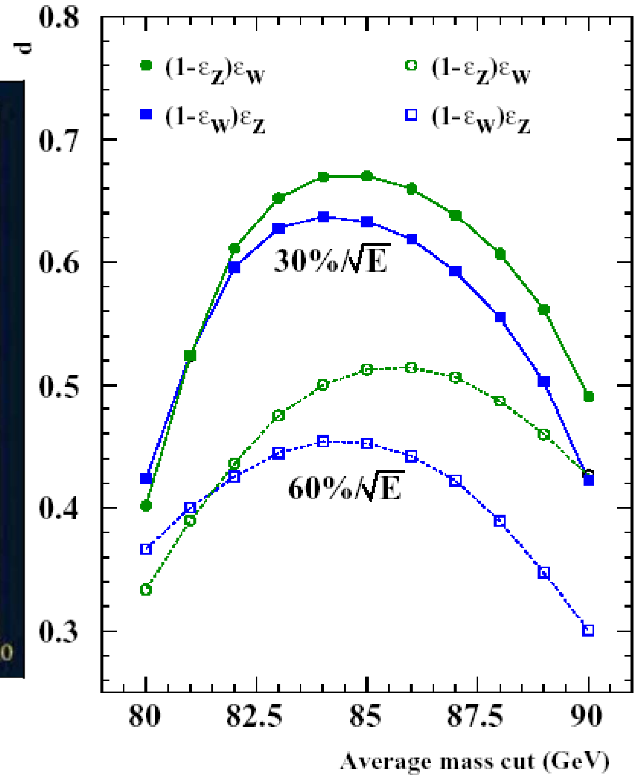
➔ **jet energy resolution ΔE≈30% √ E**

Dijet masses in WW and ZZ events





Dilution factor vs cut:
integrated luminosity equivalent



The « Particle Flow Algorithm » - PFA

In our detectors, the charged tracks are better measured than photon(s) which are themselves better measured than neutral hadron(s)

Resolution on the charged track(s)	$\Delta p/p \sim qq\ 10^{-5}$
Resolution on the photon(s)	$\Delta E/E \sim 12\%$
Resolution on the h°	$\Delta E/E \sim 45\%$

$E_{jet} = E_{charged\ tracks} + E_{\gamma} + E_{h^0}$

fraction: 65% (charged tracks), 26% (γ), 9% (h^0)

With a perfect detector, no confusion between species and individual reconstruction

$\sigma^2\,jet = \sigma^2 ch. + \sigma^2\,\gamma + \sigma^2\,h^0$ gives about $(0.14)^2\ E_{jet}$

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fraction: charged tracks 65%, γ 26%, h^0 9%

With a perfect detector, no confusion between species and individual reconstruction

$$\sigma^2_{jet} = \sigma^2_{ch.} + \sigma^2_{\gamma} + \sigma^2_{h^0} \quad \text{gives about } (0.14)^2 E_{jet}$$

Real life and real detector →

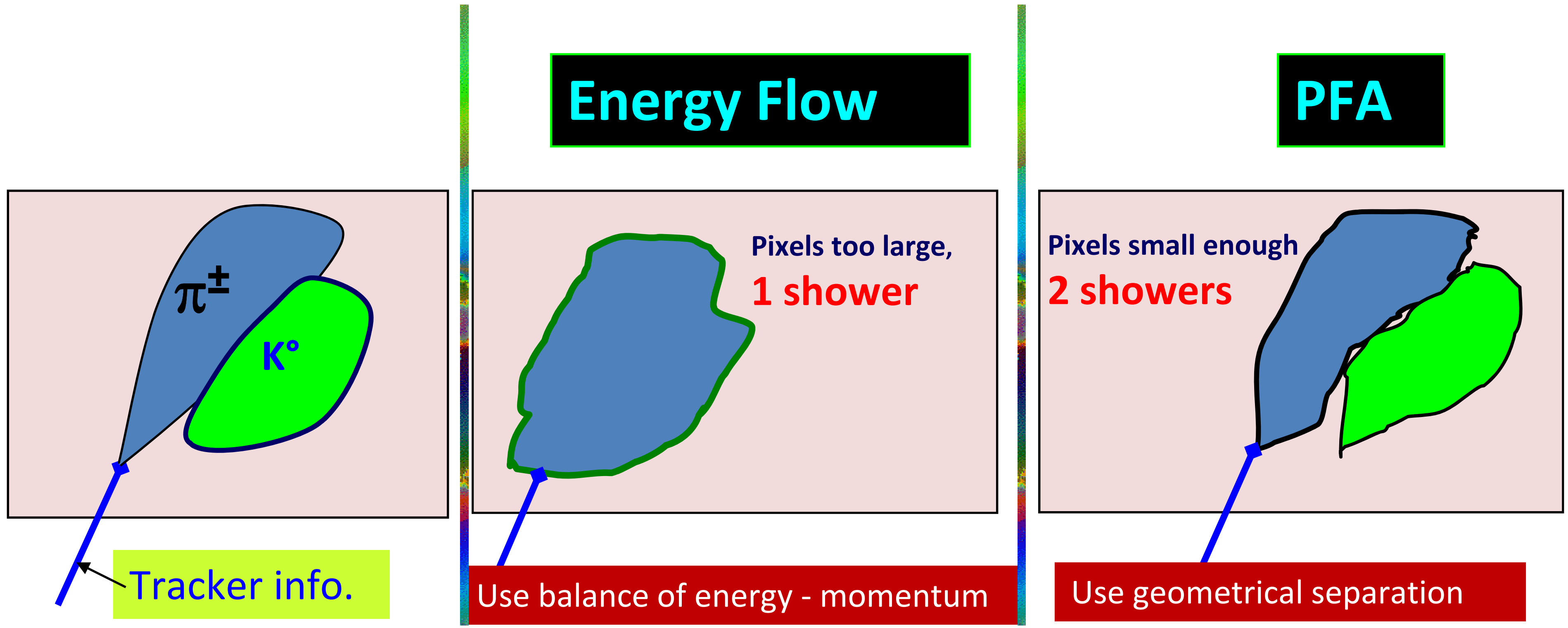
- $\sigma^2_{threshold}$ → Energy threshold to be rec. (depends on species)
- $\sigma^2_{efficiency}$ → loss of particles (not reconstructed)
- $\sigma^2_{confusion}$ → Mixing between particles in the calorimeter

PFA is NOT Energy Flow !!

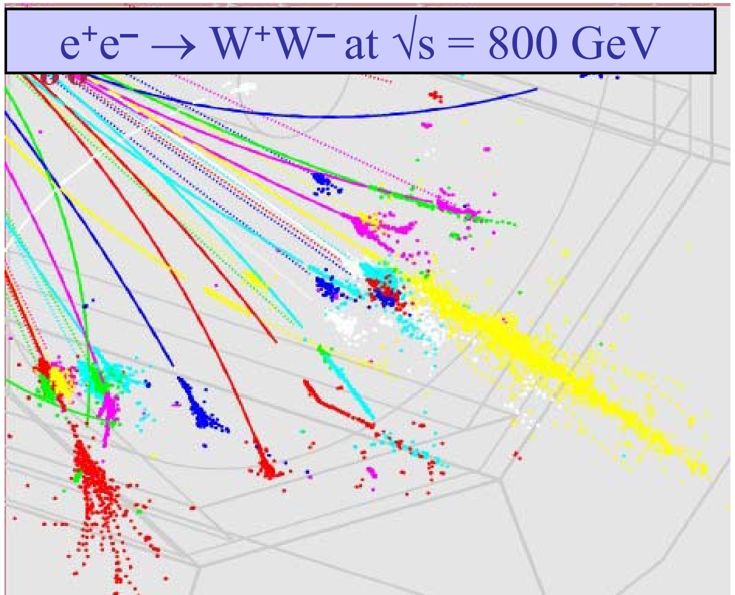
The goal : Reconstruct all particles in the event

PFA is well suited to have the best resolution on jets, and it is true as long as it is uncorrelated with particle species,........ Shower separation based ONLY on topology !!

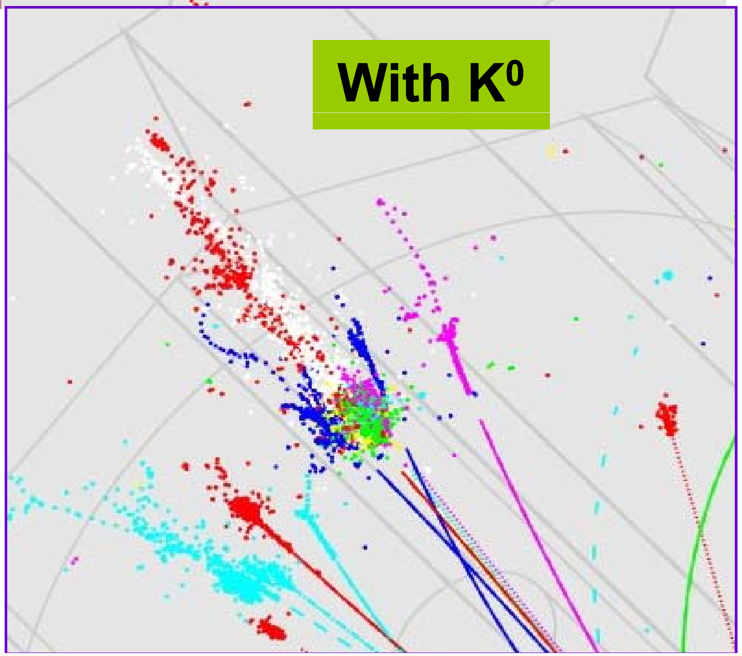
This is NOT Energy flow, where balance of energy with tracker momentum is made to extract neutral from shower with charged hadrons



Is it possible ?



Display from the true MC informations



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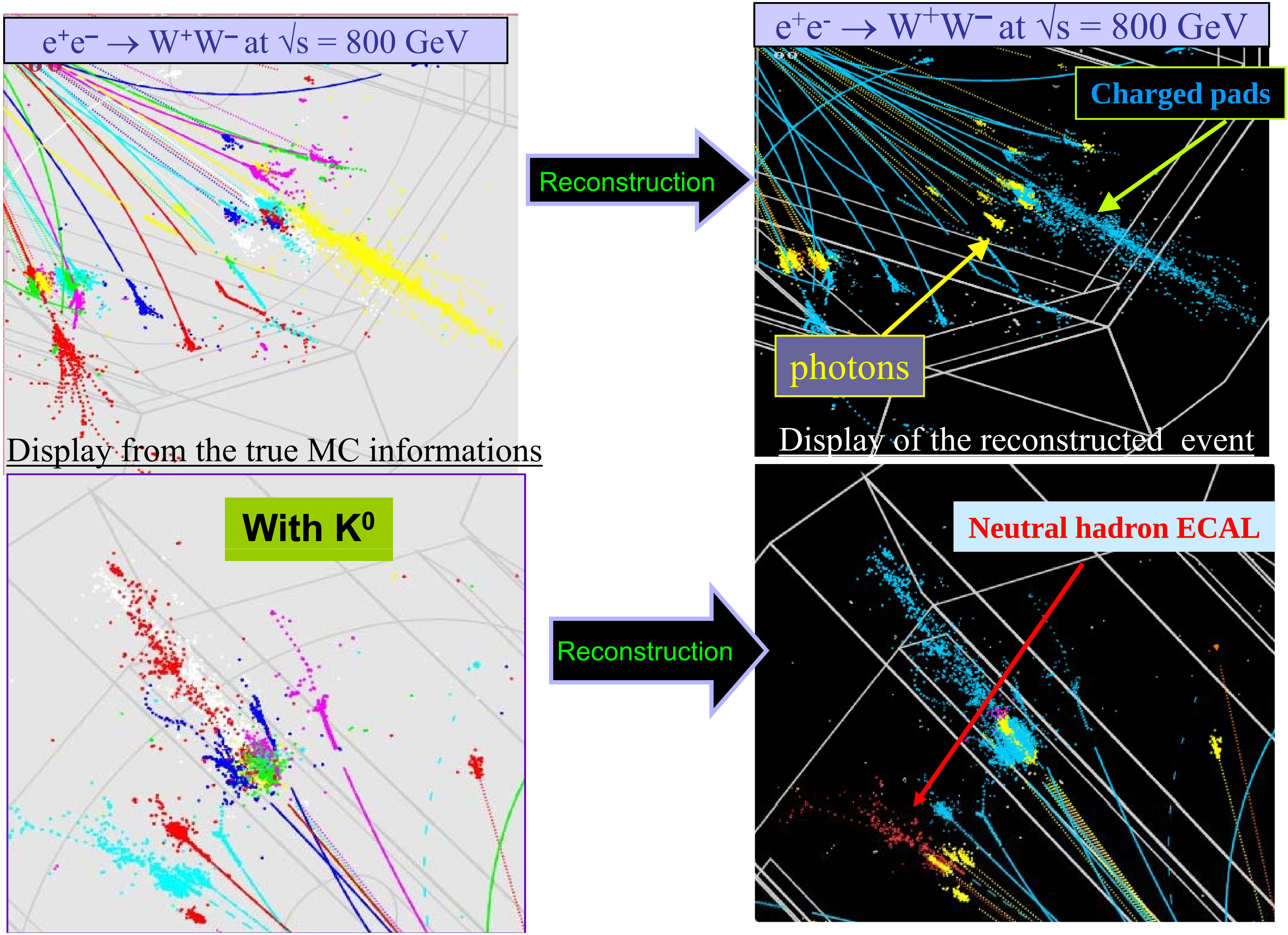
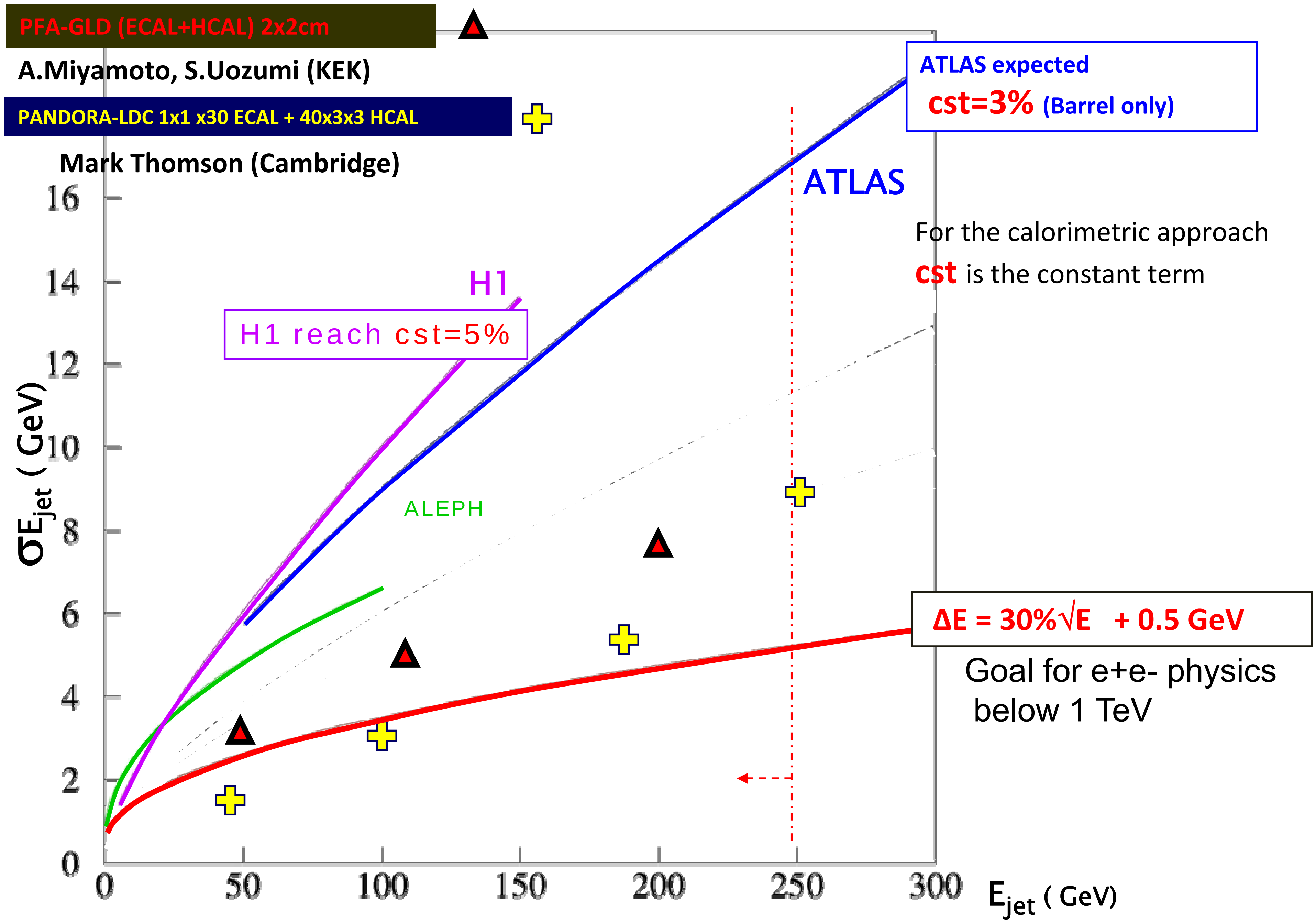
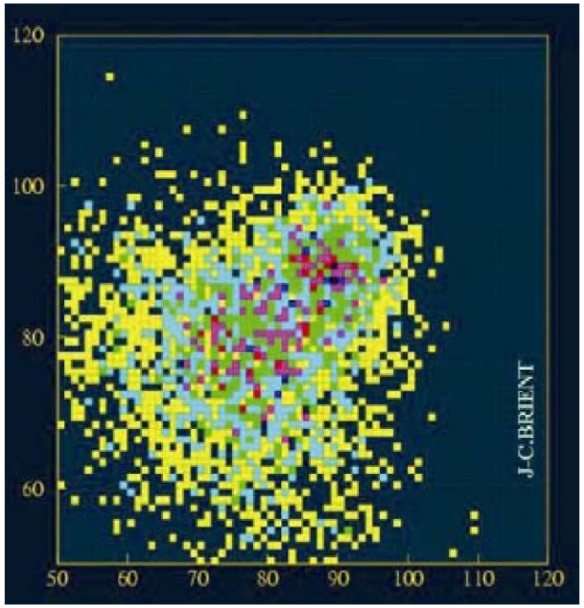
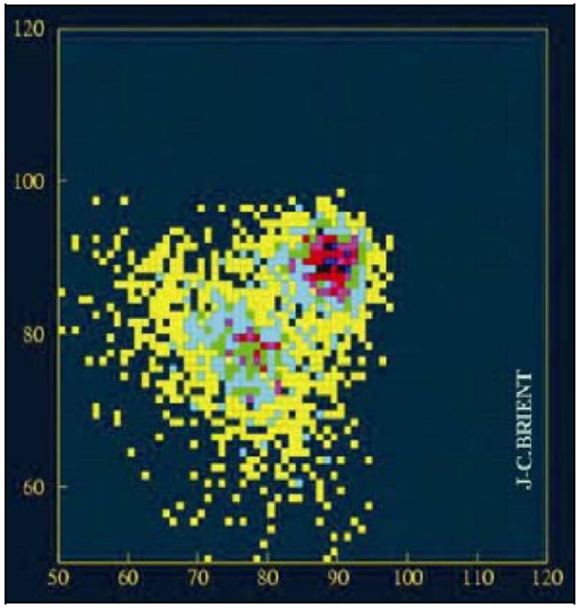




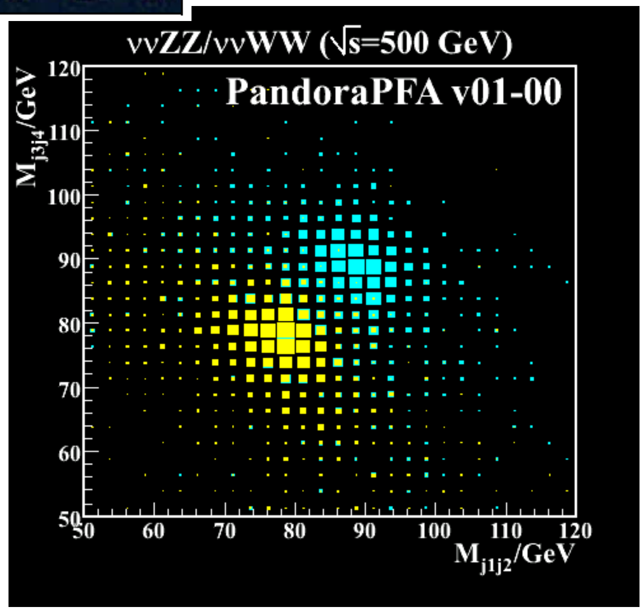
PFA-GLD (ECAL+HCAL) 2x2cm
A.Miyamoto, S.Uozumi (KEK)
PANDORA-LDC 1x1 x30 ECAL + 40x3x3 HCAL
Mark Thomson (Cambridge)
ATLAS expected
cst=3% (Barrel only)
ATLAS
For the calorimetric approach
cst is the constant term
H1
H1 reach cst=5%
ALEPH
ΔE = 30%√E + 0.5 GeV
Goal for e+e- physics below 1 TeV
σE_jet (GeV)
E_jet (GeV)
0
2
4
6
8
10
12
14
16
50
100
150
200
250
300

on e^+e^- interaction : WW , ZZ production



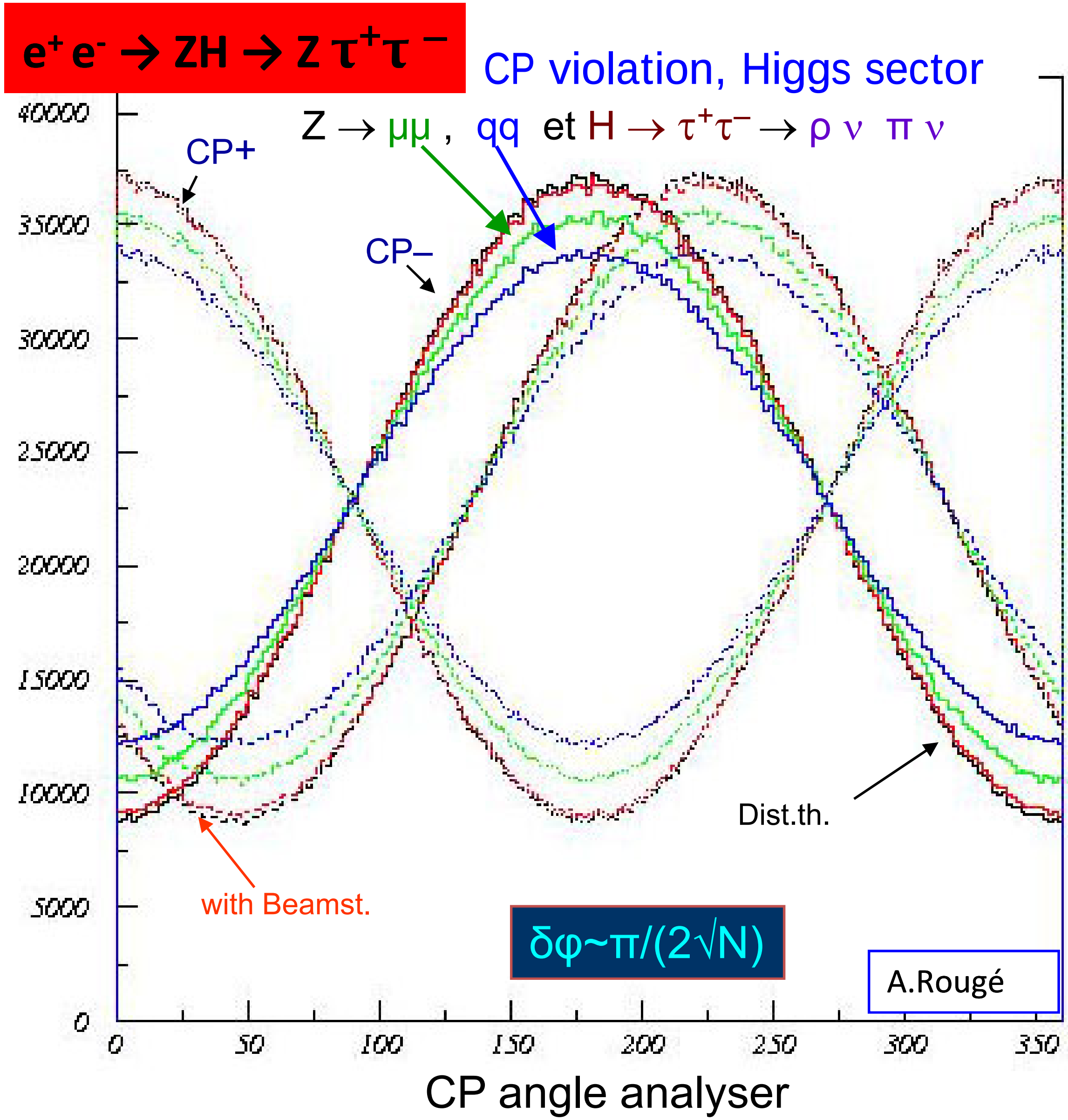


FAST simulation
(but taking into account pairing,
Neutrinos, fiducial volume,
effic. (E) per species, etc...)



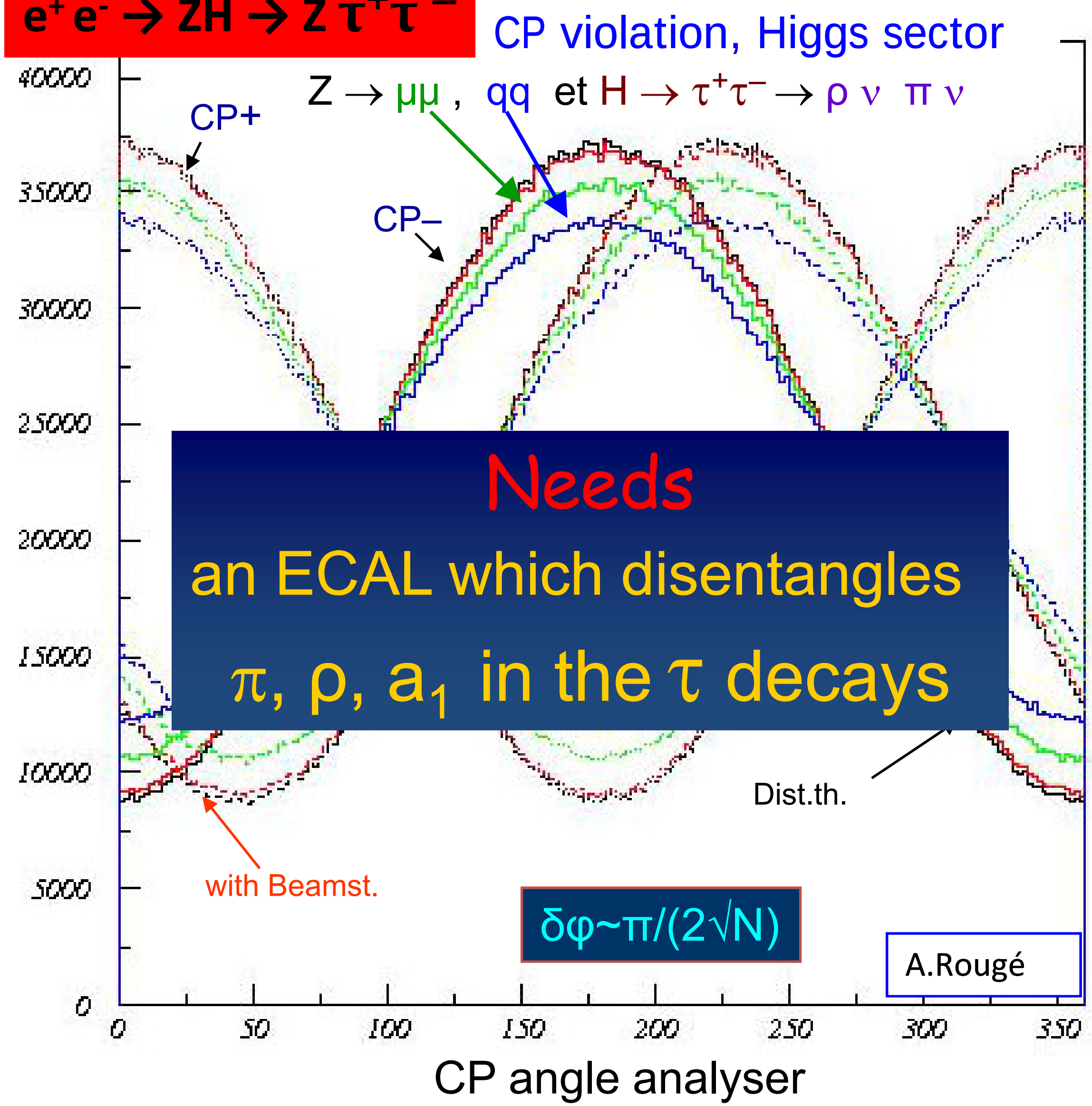
Full simulation GEANT4
with **PFA reconstruction**

on e+e- interaction : τ± as a polarisation analyser



on e+e- interaction : $\tau^{\pm}$ as a polarisation analyser

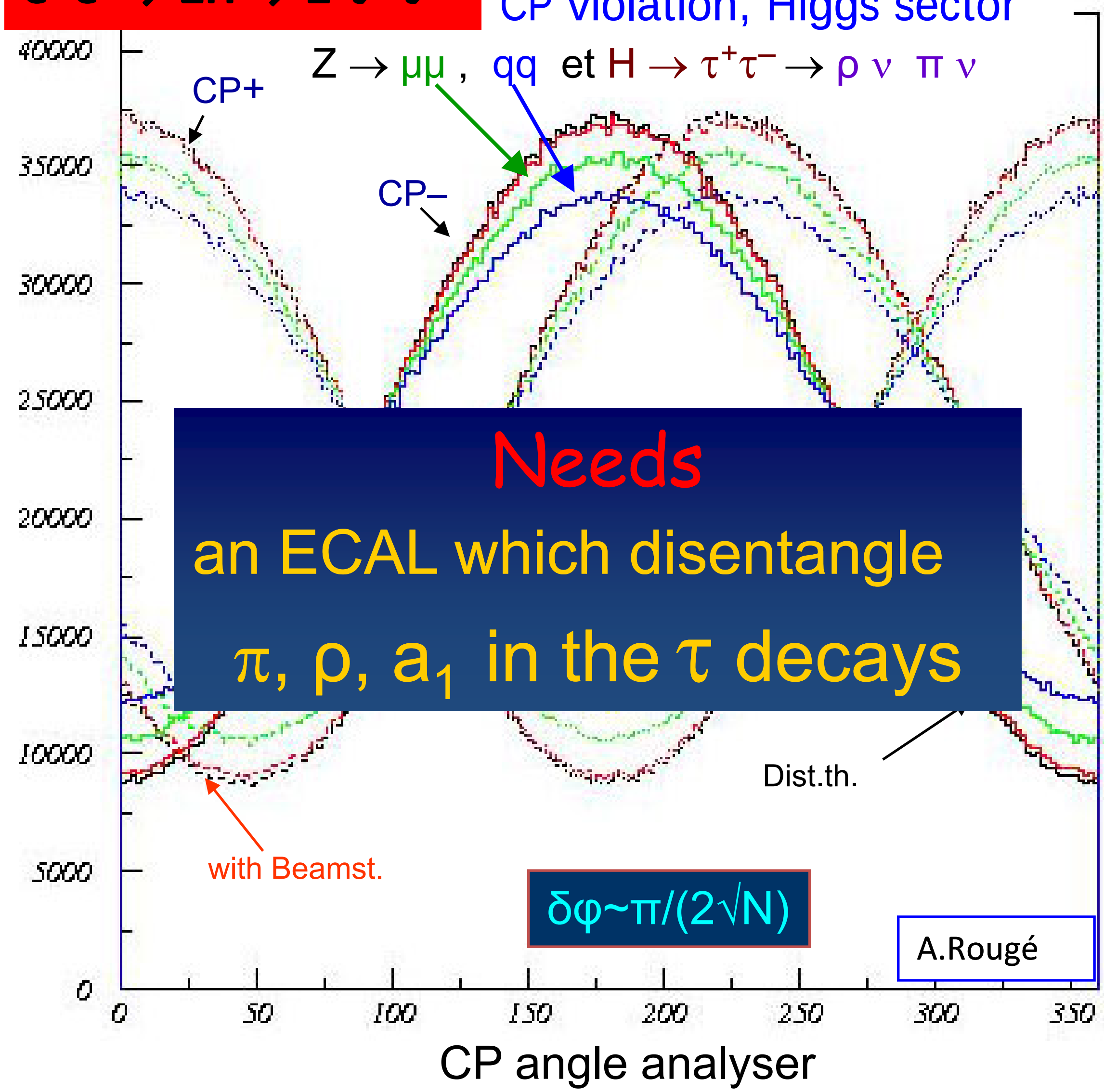
$e^+ e^- \rightarrow ZH \rightarrow Z\,\tau^+\tau^-$



on e+e- interaction : $\tau^{\pm}$ as a polarisation analyser

$e^+e^- \rightarrow ZH \rightarrow Z\,\tau^+\tau^-$

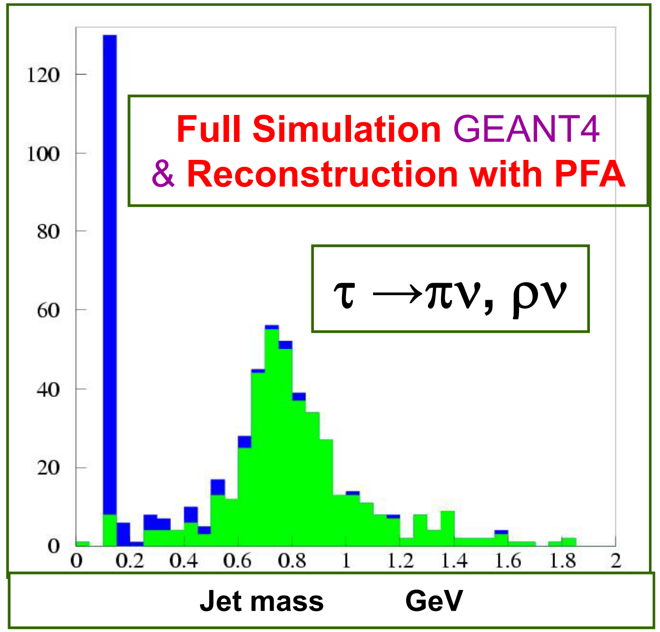
CP violation, Higgs sector



Needs

an ECAL which disentangle

π, ρ, a_1 in the τ decays

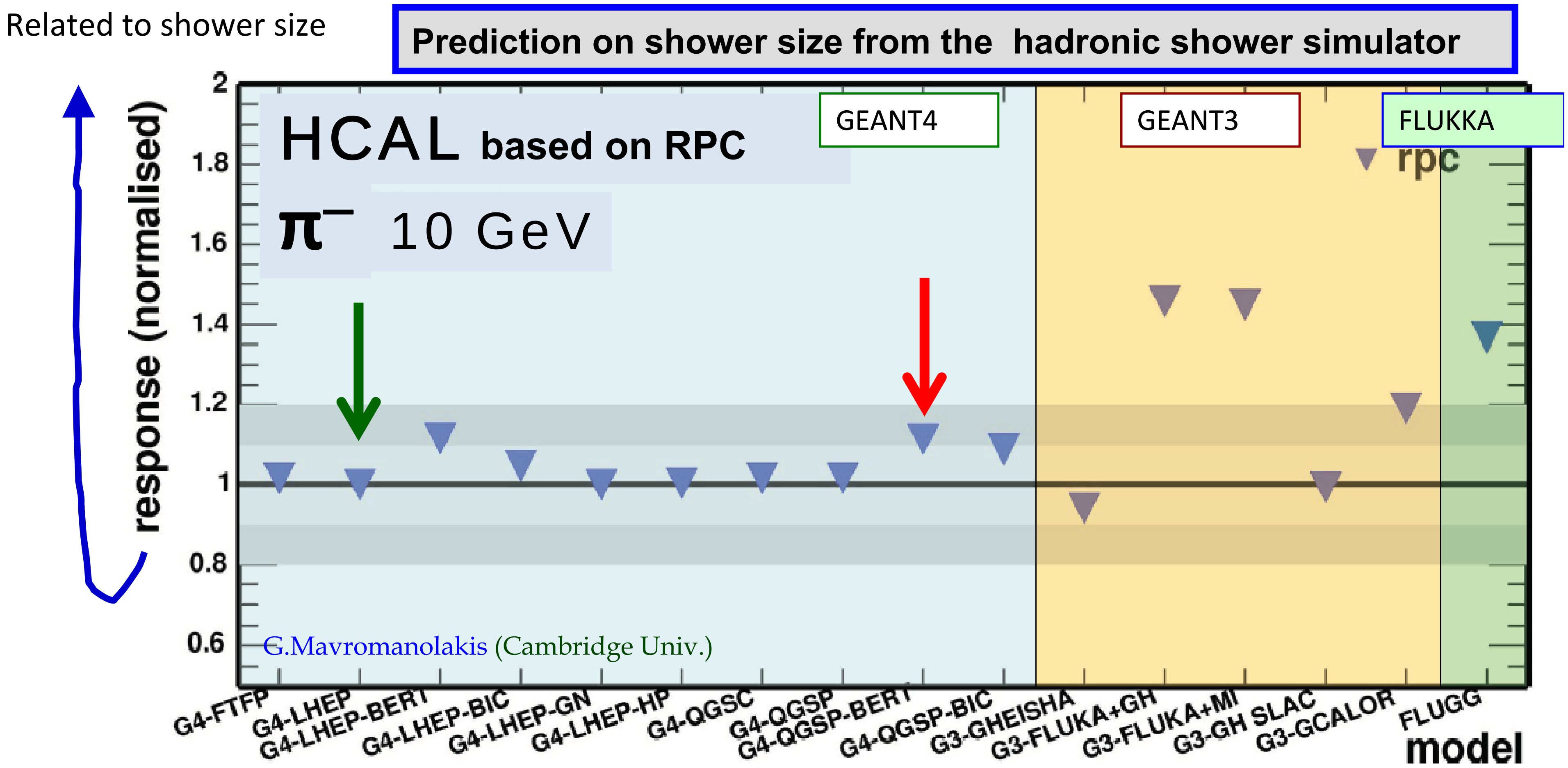


	Jet mass < 0.2	Jet mass in 0.2-2
$\tau \rightarrow \pi\nu$	82%	17%
$\tau \rightarrow \rho\nu$	2%	90%

Selection efficiency

PFA feasibility uncertainties

How the PFA performances depend on the hadronic shower model ?



M.Thomson (Cambridge Univ.)

(PandoraPFAv02 +trackCheater)		E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$
LDC00Sc	QGSP_BERT	45 GeV	22.6 %
LDC00Sc	LHEP	45 GeV	23.2 %
LDC00Sc	QGSP_BERT	100 GeV	29.3 %
LDC00Sc	LHEP	100 GeV	30.2 %

It is not an answer but a first indication

....

Built prototypes with the technology useable for PFA detector and goes to test beam to constraint the hadronic shower models

(However, do not hope to have one single hadronic shower list working nicely for everything)

.....

CALICE test beam with pion from very low energy 1GeV up to 100 GeV

cf talk by E.Garutti

Calorimeters optimised for PFA → CAlorimeters for the LInear Collider Experiment

Calorimeters optimised for PFA → **CAlorimeters for the LInear Collider Experiment**

Calorimeter for ILC

May 2008

281 phys./eng.
47 institutes
12 countries

Design and test calorimeters (ECAL,HCAL) optimised for PFA

↓

Test beam at DESY, CERN and Fermilab

Partially funded by EU (EUDET)

Granularity (lateral) → Separate particles

Segmentation (in depth) → pattern of the shower (no shower confusion)

Large distance from IP → Open the jets

Large B field → The bending separate h° , γ from $h^{\pm}$

ECAL and HCAL inside the coil

a) Very high granularity device i.e. 120 Mchannels for an ECAL (cells $5x5mm^2$)
b) Very compact calorimeter (to avoid large coil .... Cost) i.e. ECAL is 18 cm thick
c) Prototype in test beam is the only way to debug the concept and design

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a)

→ **Embedded VFE,FE,ADC**) ....
Local zero supress, Low power dissipation

→ VERY good S/B at low S (mip)

→ STRICT control of the common mode !!

→ **VERY STABLE response with time, temp., etc...**
(or way to control the calibration)

→ **A DAQ system able to manage this very high number of channels**

cf talk by Ch. De la Taille

cf talk by A.Lucaci-Timoce

cf talk by V.Bartsch

b)

→ very high density of channels (about 256 channels in 8 cm3)

c)

→ **Test beam at DESY, CERN and now Fermilab**

cf talk by F. Salvatore

The proposed solutions

ECAL : Sampling calorimeter

Solution 1 :

Tungsten (density) - silicon (pixel size < Molière radius)

Pixels size 5x5mm² and 30 readout layers
(86 Millions channels) or even MAPS

cf talk by R.Cornat

Solution 2 :

Tungsten - MPPC and scintillator strip

Scint. Strip 1x4 cm X, Y and 30 readout layers
(about 5 Millions channels)

cf talk by D.Jeans

HCAL

Solution 1 :

Sampling calorimeter tungsten/Stainless steel (density) –digital readout (pixel size)

Pixel size 1cm² and about 40 readout layers
(~50 Millions channels)

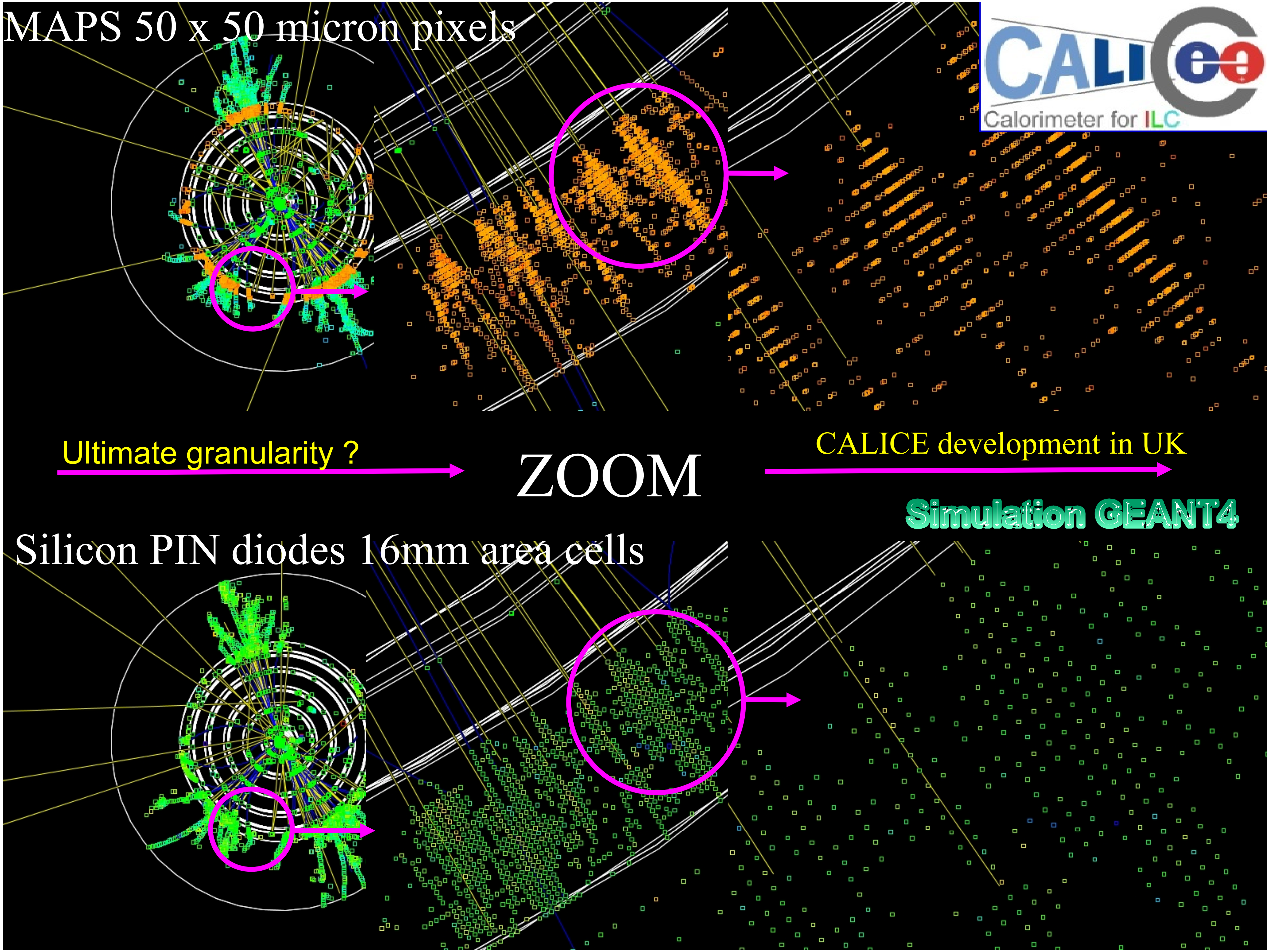
cf talks by J.Repond
by I. Laktineh

Solution 2 :

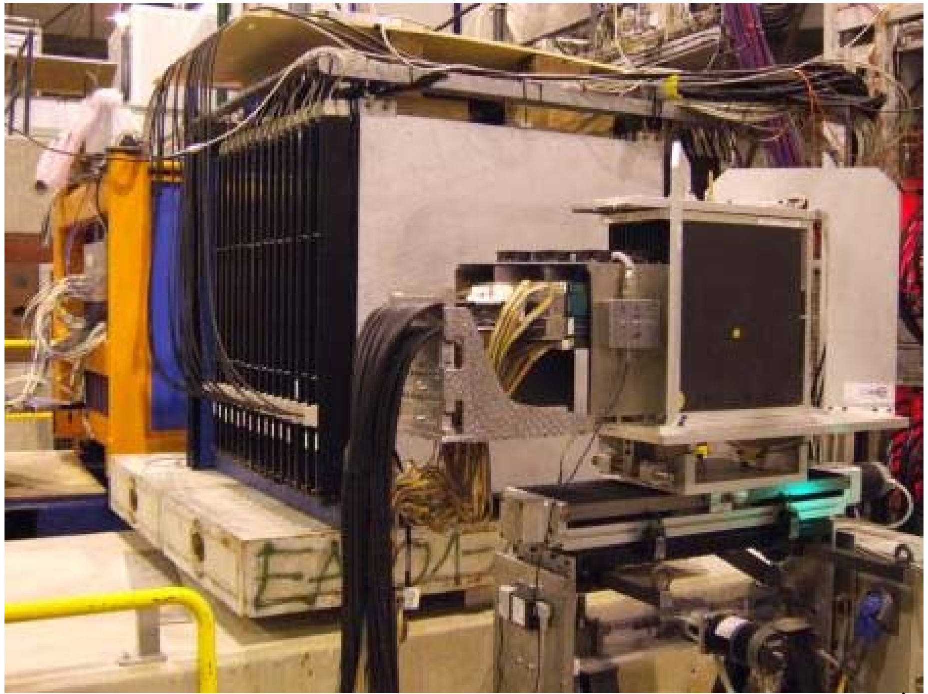
Sampling calorimeter tungsten/Stainless steel (density) – scintillator tile (small size)

Pixels size 9 cm² and about 40 readout layers
readout by silicon PM !!

cf talk by F.Sefkow

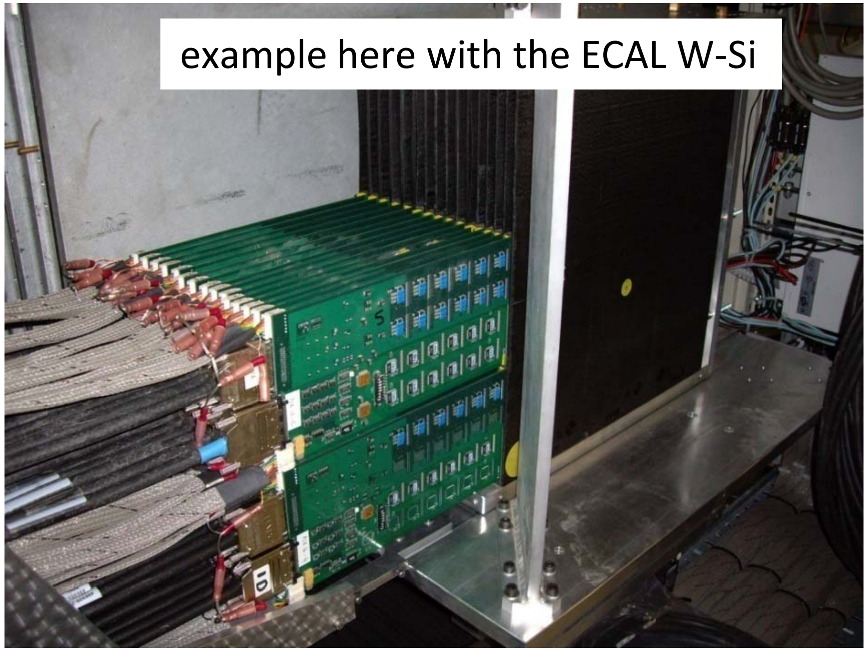

MAPS 50 x 50 micron pixels
Calorimeter for ILC
Ultimate granularity ?
ZOOM
CALICE development in UK
Simulation GEANT4
Silicon PIN diodes 16mm area cells

2006 – 2007 CERN Test Beam with electrons, pions



Dense & Complex but

It is a fantastic tool



TB for ECAL solution 1, Analysis of the **electron test beam** are close to the publication

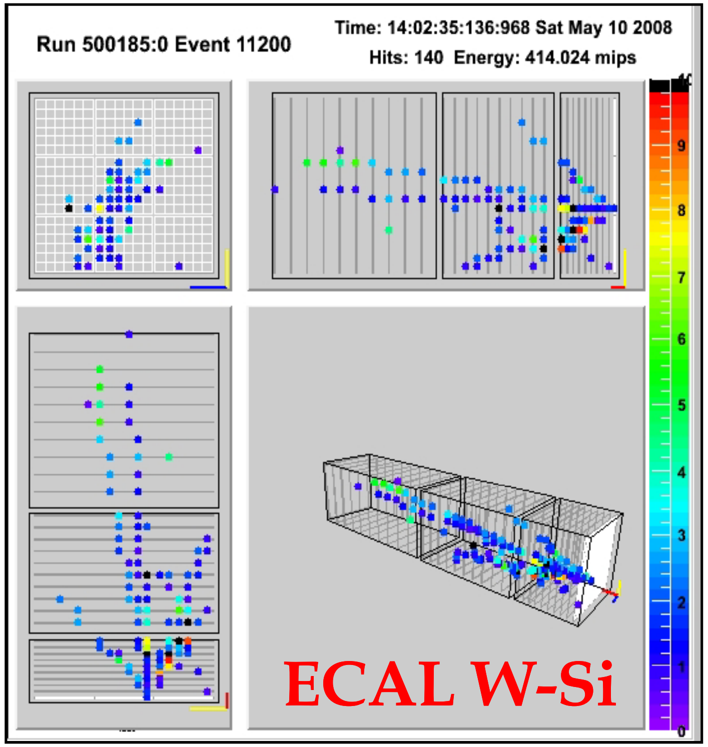
MC/ real data at 2%

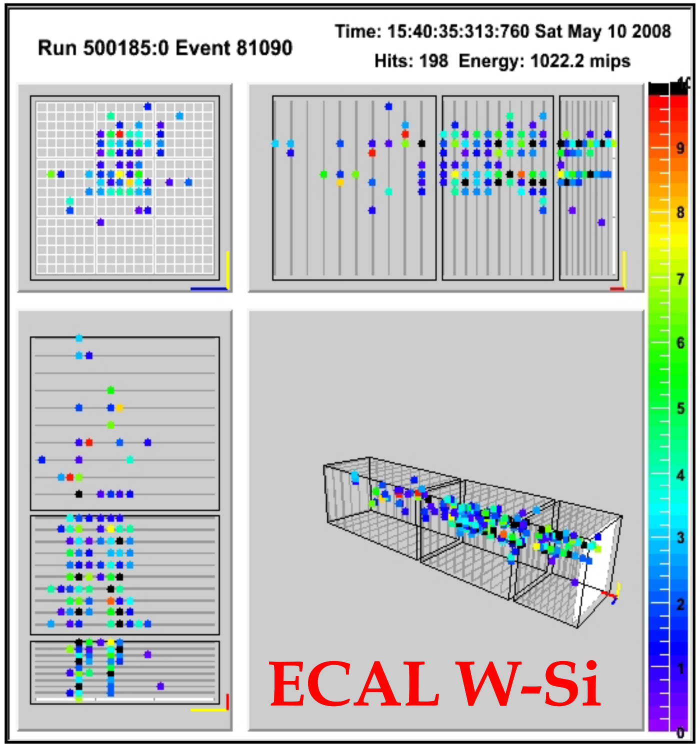
cf talk by D.Boumediene

- 30 readout layers in 20 cm
- 9720 channels in 18x18x20 cm3
- S/N at mip at about 8

NEXT (>2008) the hadrons response

FNAL 8 GeV pion beam



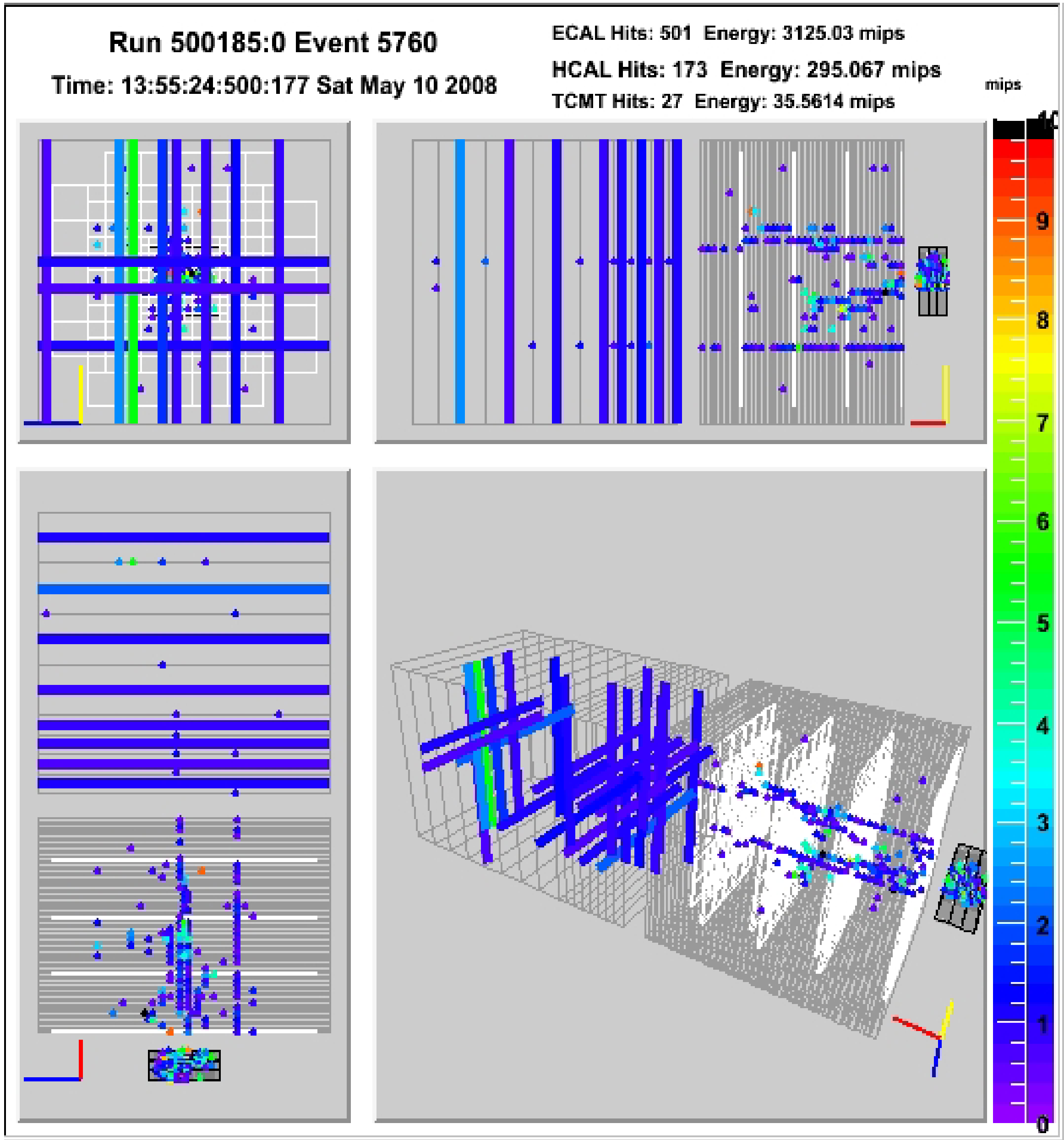


First study indicate that

1- software compensation would be feasible

2- Neutrons measurement could be done with time information vs E

Hardware compensation is not the only way to have compensation

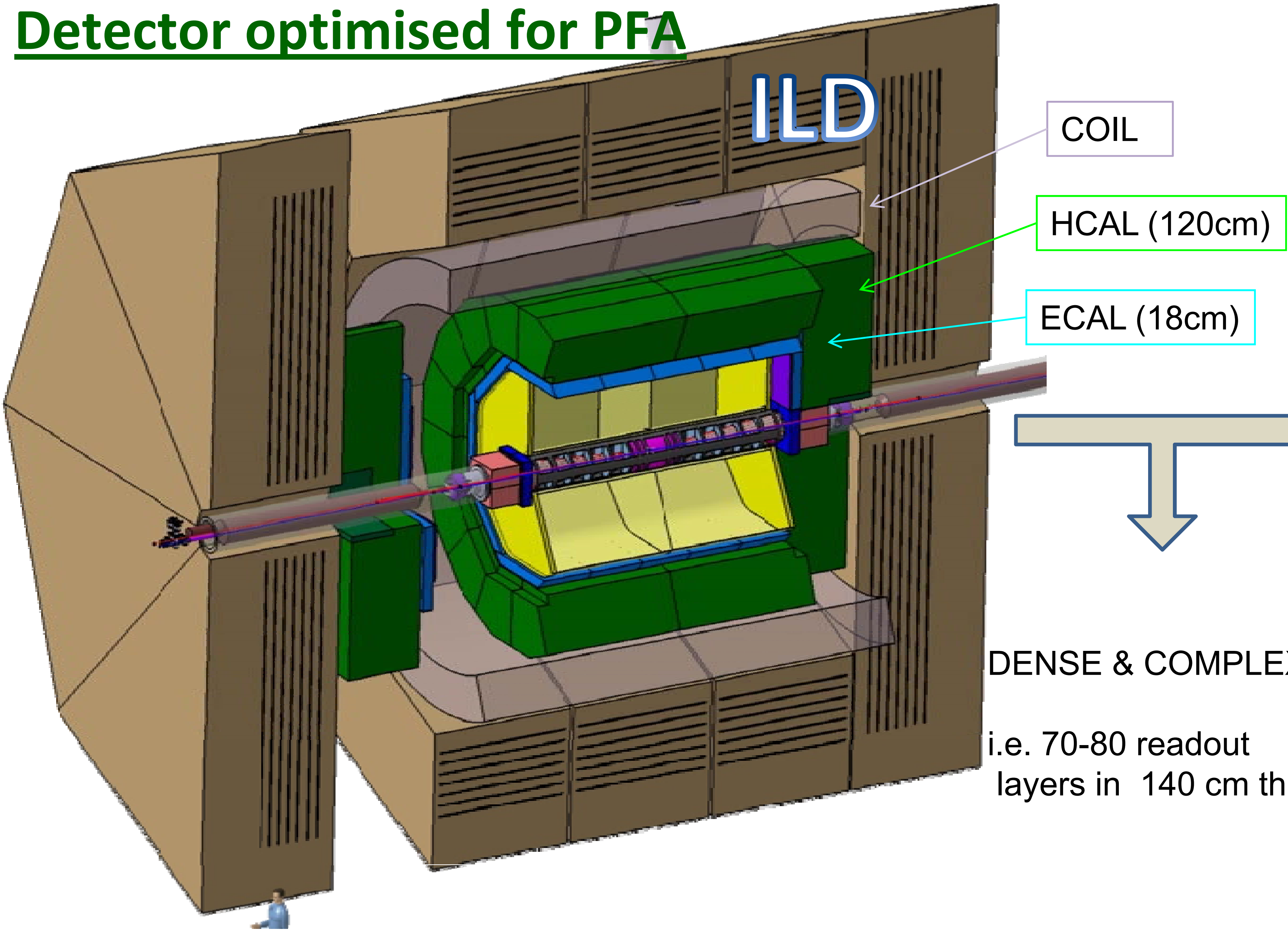


Pion Test Beam MTBF-Fermilab

ECAL (solution 1)
HCAL (solution 2)
& a Tail Catcher Muon Tagger

Low energy pions beam
....
It will have strong impact
On GEANT4 hadronic shower
In near future

Detector optimised for PFA



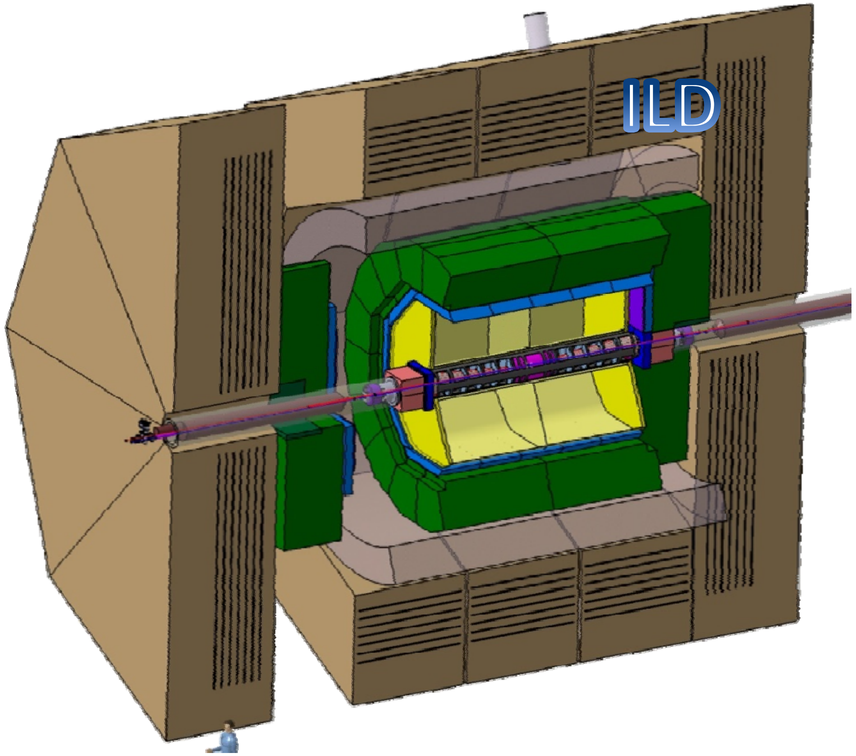
DENSE & COMPLEX

i.e. 70-80 readout layers in 140 cm thick

Detector optimised for PFA

The calorimeter is the central part and the reconstruction software is essential

The pattern recognition in the calorimeter is the core of the PFA performances



The cost and complexity
of the calorimeter is largely dominant

Cost fraction
1/3 for the coil
1/3 for the calorimeter
1/3 for the rest

Ready for LOI expected at mid 2009

It is however important to notice that these R&D for PFA calorimeter are **strongly generic** ....

From electronics to PFA, from CFI mechanics to DAQ new generation ....

Conclusion

- optimising for PFA give a new view on the calorimeters
.. *the duty list is different*

- The optimisation goes through software .... Not so easy
one need to disentangle what is for proposed device and the part related to the software

- The calorimeter is more than ever the central part of the detector

- The proposed solution are ultra high granularity device as well as for ECAL than for HCAL

- The CALICE collaboration propose to design, built and test prototypes
& results begin to arrive

10 years after the proposal to use PFA for ILC
I am happy to see that LHC, TeVatron,... use or are expected to use it