A W-Si calorimeter for Higgs physics

The studies held in the framework of the ECFA-DESY workshops for a linear electron collider have shown that a very dense high granularity calorimeter would be the optimal solution for studying the Higgs.

A design for such a calorimeter, in tungsten-silicon for the electromagnetic part, purely digital for the hadronic part, is presented here with some of its expected performances.

Tesla TDR to be released in March-April 2001
for physics, accelerator and detector

TESLA as a linear collider

An electron-positron linear collider in the range from Z to 1TeV

One main goal, the study of the Higgs, branching ratios ..

The study of the top

Subsidiary, search for new physics,
study of electroweak physics

A many jet physics

Partial loss of the beam energy constraint

A detector for energy flow

⇒ for the calorimeters

Excellent hermeticity, angular and in depth

A good energy resolution

An excellent lepton identification

An excellent granularity

A good jet analysis through a full pattern reconstruction

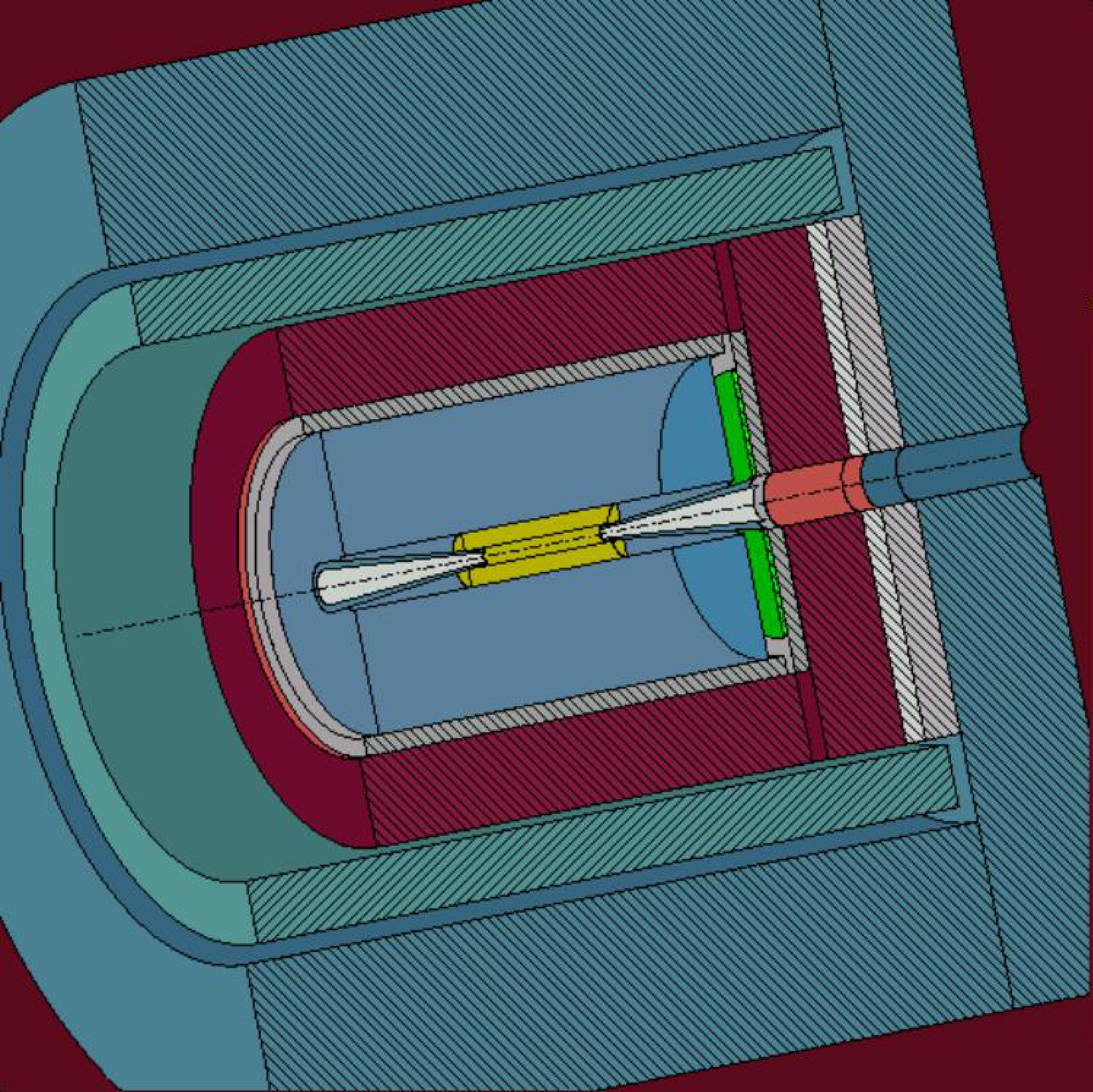
Through

A pictorial calorimeter totally inside the coil

A high density ECAL W-Si with tiny cells

A digital HCAL with tiny cells

TESLA detector



Conceptual drawing

Yoke

4T Coil

HCAL

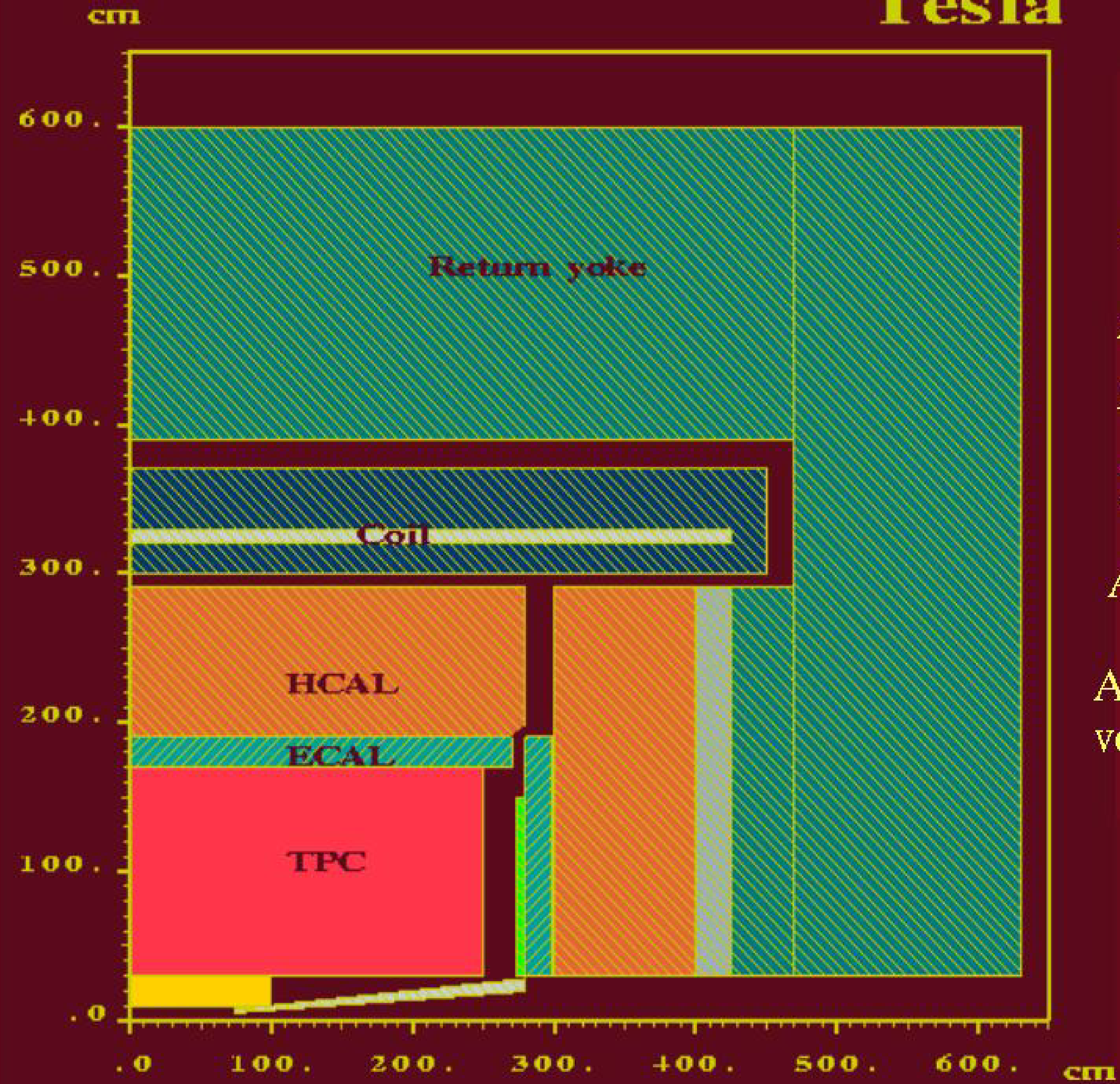
ECAL

TPC

IT

Masks

Tesla



TESLA

An instrumented return yoke

A 4T field

More than 5 λ_I inside coil

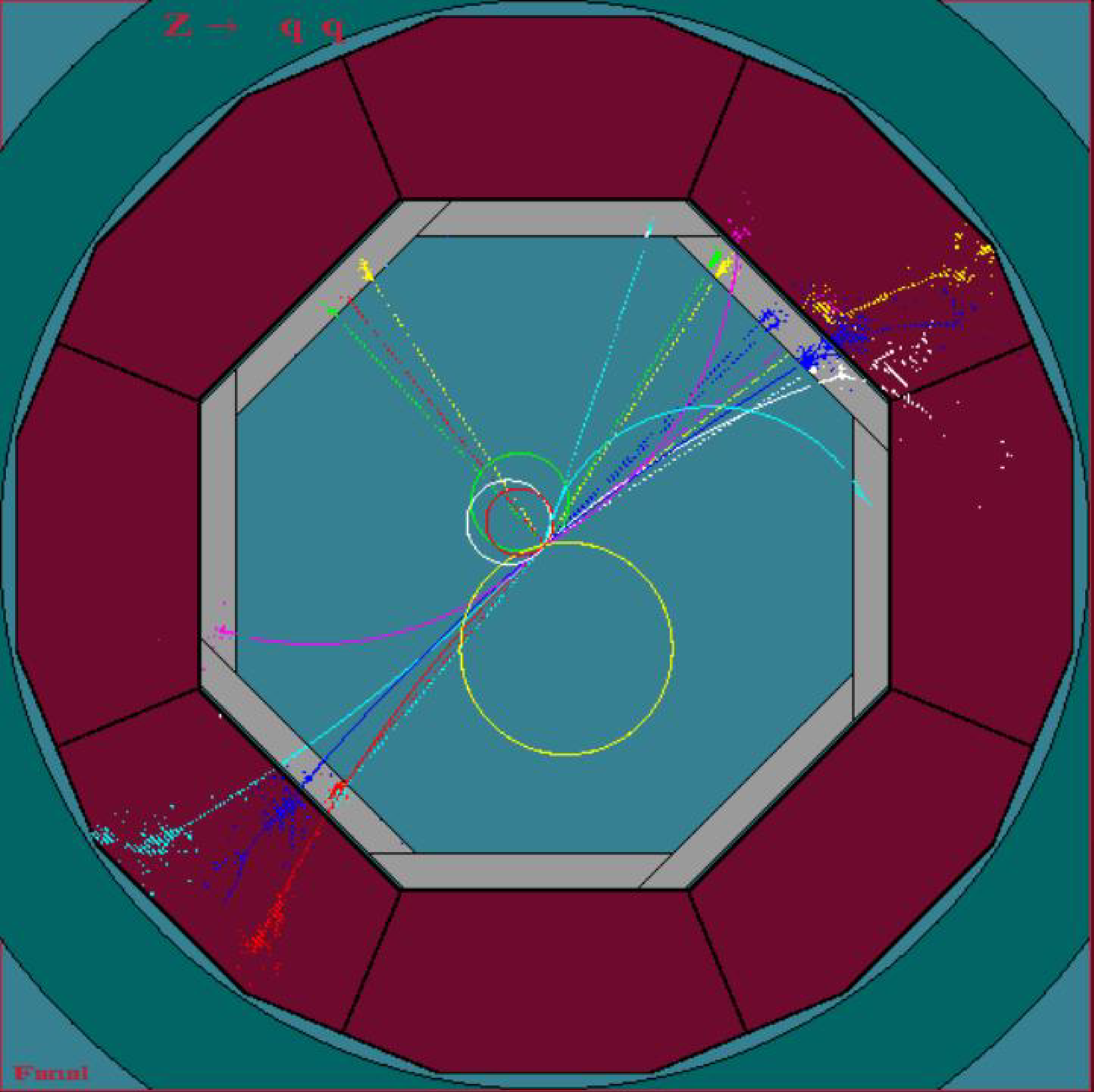
24 X_0 of W-Si ECAL

A TPC with small pads

A vertex detector
very close to the interaction

Masks

View of an event in such a detector



Coil

HCAL

ECAL

Simulation Mokka
based on GEANT4

Graphics Fanal

Measuring jets

Consider jets

Energy spectra quite similar to LEP

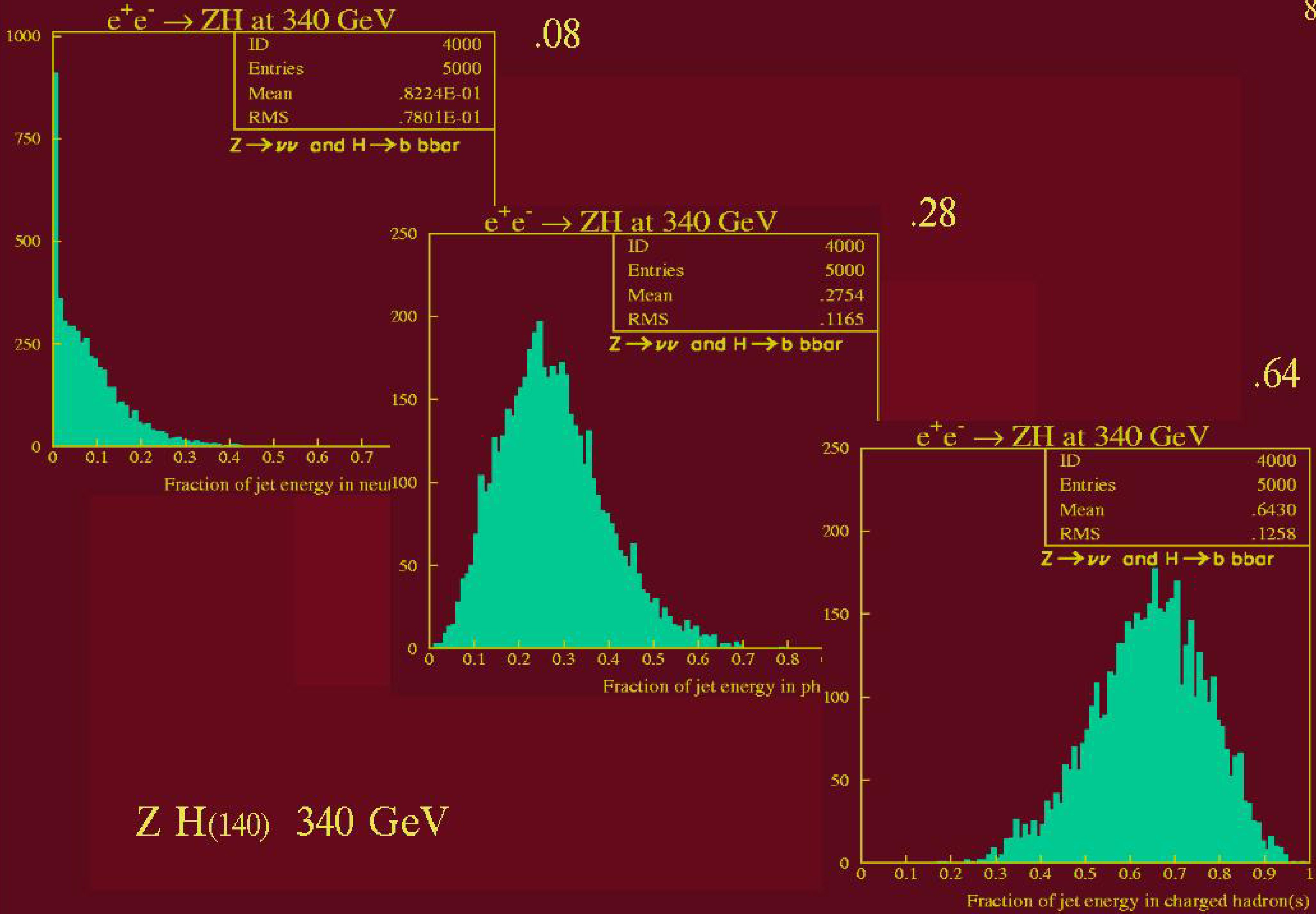
Impact of a 4T field needed to clear up the machine background

Measuring systems of jets masses means measuring **jet energies** and **angles**

The presence of ν 's is signed by the presence of charged leptons, e, μ or τ

They come from decays of b's or c's.

Good ECAL granularity and resolution for e
good HCAL granularity for muons
both for taus.

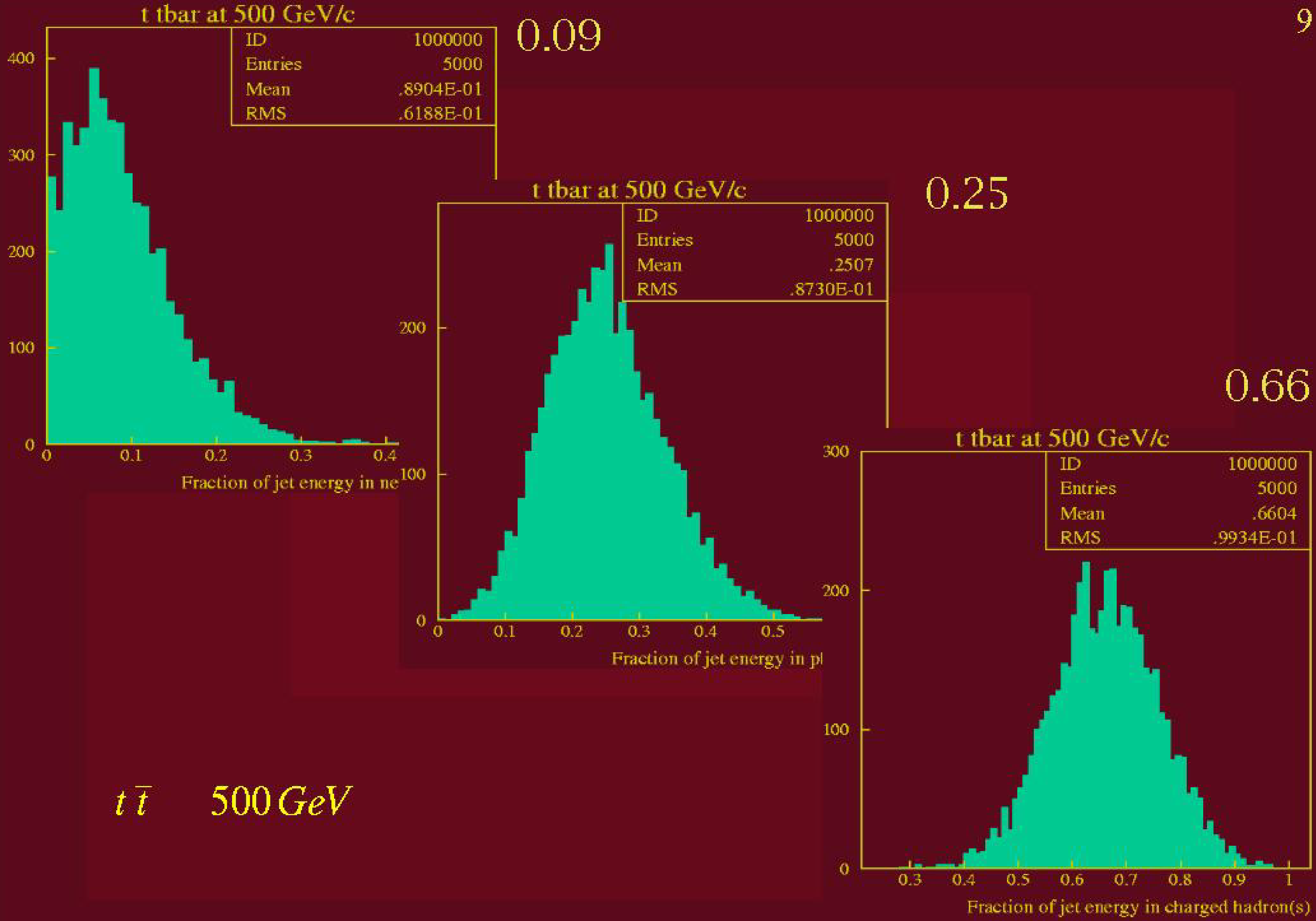


.08

.28

.64

Z H(140) 340 GeV



$t\,\bar{t}$ $\quad 500\,GeV$

A simple exercise: consider a 100 GeV jet without leptons

It contains in means 60 % charged track energy
30 % gamma energy
10 % neutral hadron energy

Global method

We can measure all the energy by calorimetry

Gamma energy purely in the ECAL with the ECAL resolution

Hadronic energy, charged and neutral, in the ECAL and HCAL with hadronic resolution

Role of the noise term

Examples of resolutions:

Electromagnetic $\delta E = 0.10 \times \sqrt{E} \oplus 0.005 \times E$

Hadronic $\delta E = 0.40 \times \sqrt{E} \oplus 0.03 \times E$

Expected jet energy width: 4 GeV

This would be excellent but

Measuring the energy purely by calorimetry

Global method

High field ⇒ low energy tracks (<1 GeV) escape detection
correction, picking tracks?

Such a good hadronic resolution can be achieved by hardware
or software compensation.

Hardware implies a much worse electromagnetic resolution,
is a good electromagnetic resolution needed?

Software means that the coefficient of the ECAL energy depends on
the nature of the particle. Needs separation ⇒ analytic.

Anyway the energy resolution will not be better than 4-5%.

Second point, we are interested in measuring jet masses more than energies.

This means angles!

The high field spoils completely the one jet mass, but who cares, mjet = 0 in first approximation

A two jet mass will be defined from the energies and the angle. Some granularity

Angle spoiled by field and energy fluctuation.

And when the jets overlap!

We can try to measure the jets by separating the charged tracks, the gammas, the neutral hadrons

Analytic method

The uncertainty on the energy is $\delta E = \delta E_c \oplus \delta E_\gamma \oplus \delta E_h$

The uncertainty on charged particles can be neglected but for
the efficiency (0.997),
the fake tracks,
the electrons

Tails

Expected jet energy resolution 1.4 %, dominated by hadronic, 0.6 % 1.3 %

The angle measurement will also be good

BUT this needs a "perfect" separation between the three categories

Efficiency for each of them, fakes, distorsion of the energy

This requires best granularity, lateral and longitudinal, best hadronic resolution

Electromagnetic resolution may not be that important: 1.6 % for a stochastic term of 0.15

Separating photons close to charged particles

The efficiency the fakes

Measuring their energy

Effect of clustering and measuring from the core (18 to 25 in ALEPH)

Sharing of energy between charged tracks and gammas.

The energy for jets without neutral hadrons measured around 20 %
with an efficiency for photons above 200 MeV above 99%

The pattern contribution completely dominant
or the sharing algorithm

Much more work
in software

This is our choice

Approach for a solution

Nothing challenging in its principle

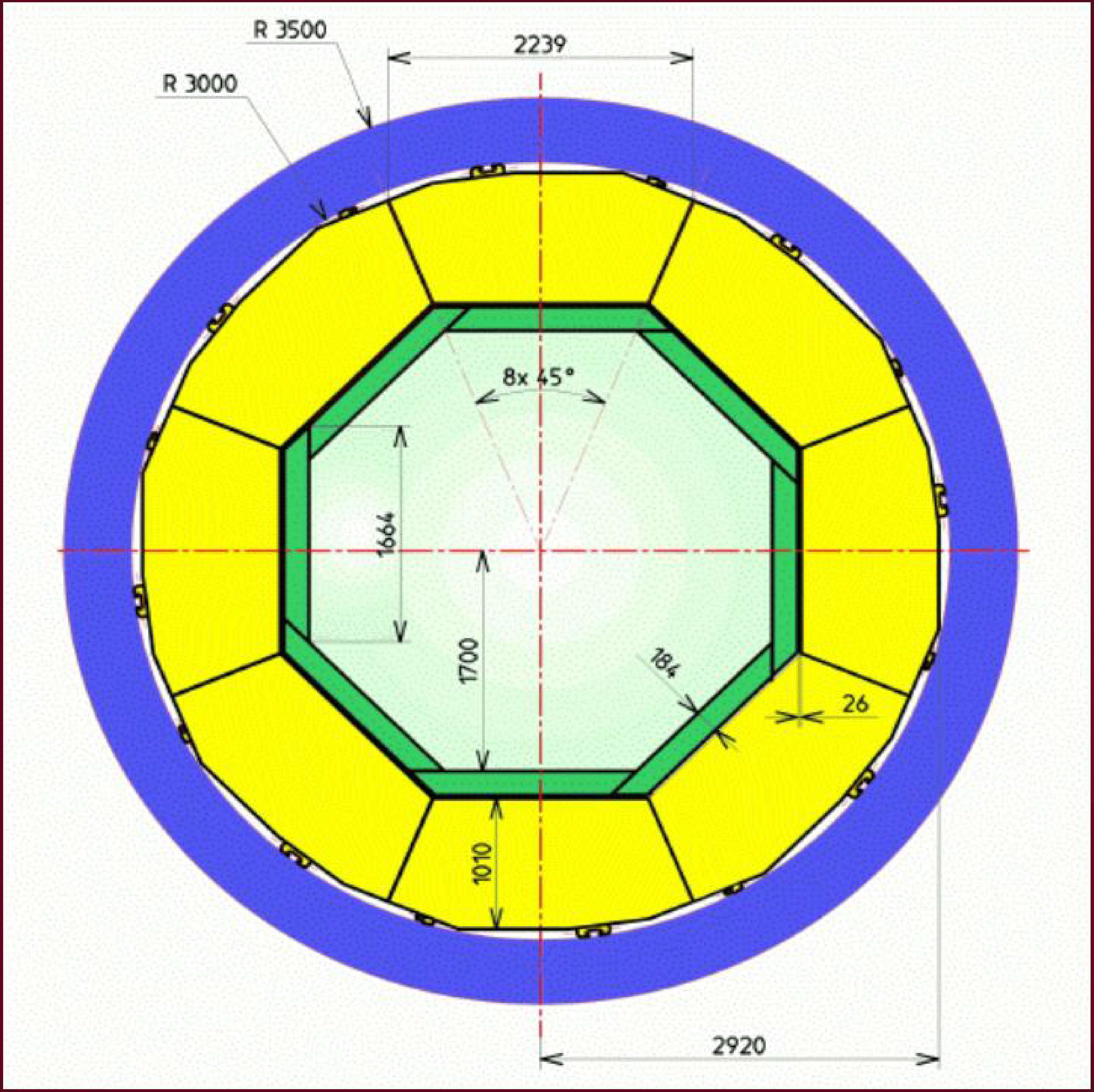
But a challenge by its complexity

A very dense electromagnetic calorimeter: W radiator, Si detector
a good area of silicon ~ 3000 m^2

No dead space by means of peculiar mechanical
geometry and structure in fiber composite

Very small cells 1x1 cm2
very numerous 32 M
no projectivity

As many cells as seconds in a year



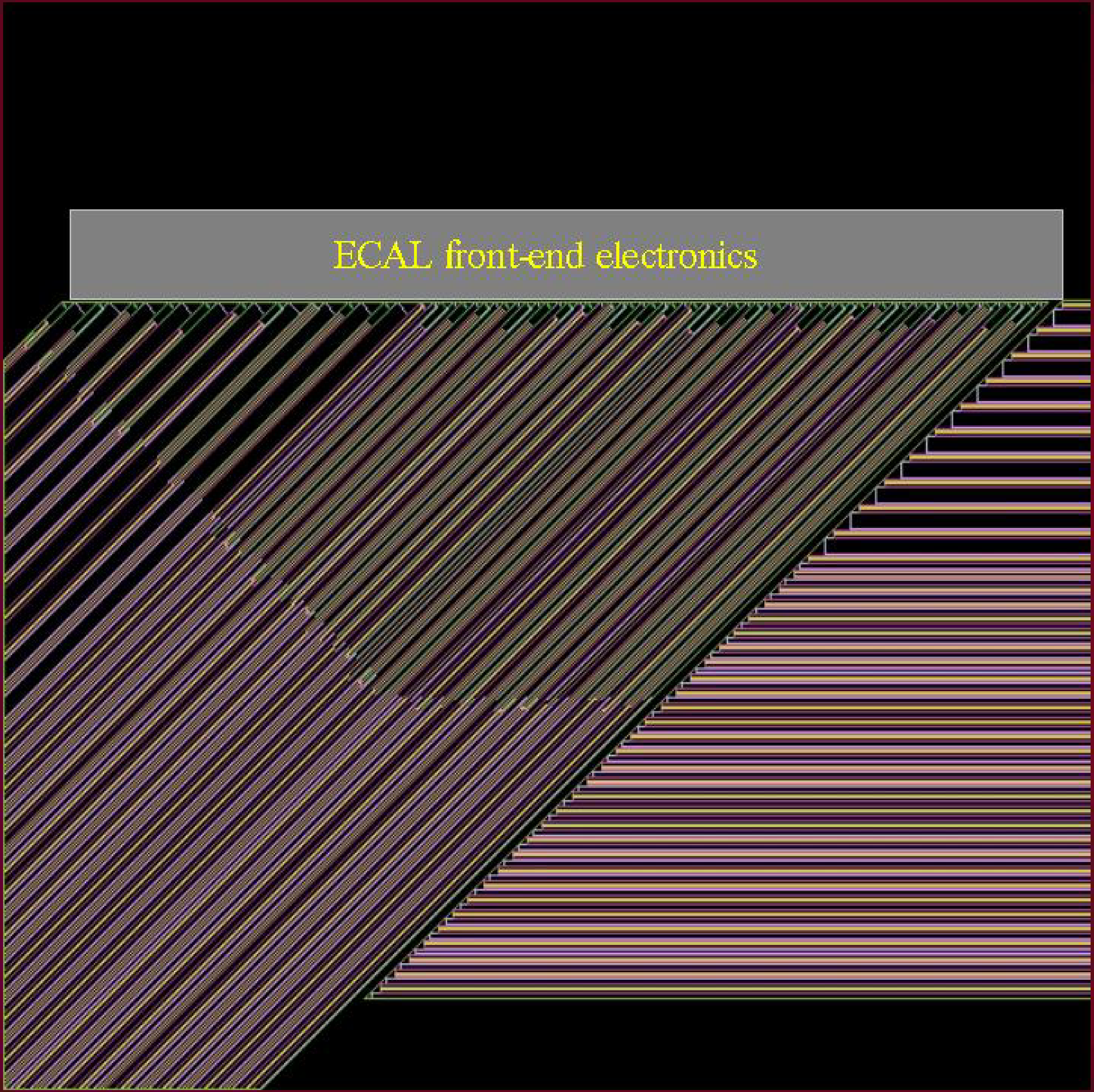
TESLA

The eight-fold way

No cracks in ϕ
for the ECAL

Thin projective cracks
for HCAL
(filled with iron)

Getting the signals out



The geometry allows to put the electronics between ECAL and HCAL
no cracks for getting the signals out

The solution to the mechanical structure

Trivial
but

No large holes for tie rods, wrt showers
but a lot of small (0.3 mm) walls

The tungsten slabs are wrapped
in an epoxy-carbon fiber composite
leaving space for detector elements

As each pad is read independently, projectivity has been dropped
in particular in the end caps which exhibit an x-y structure

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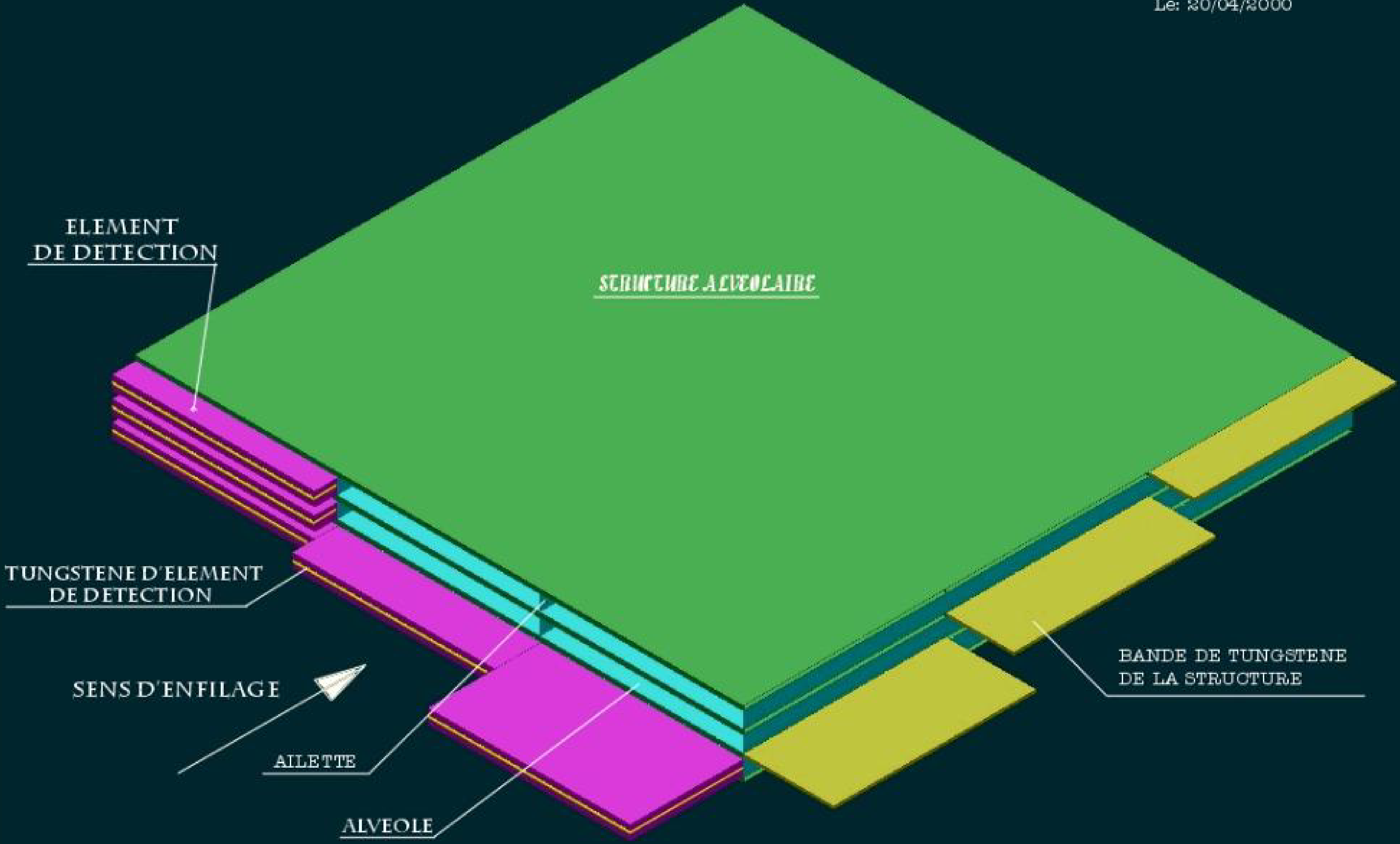
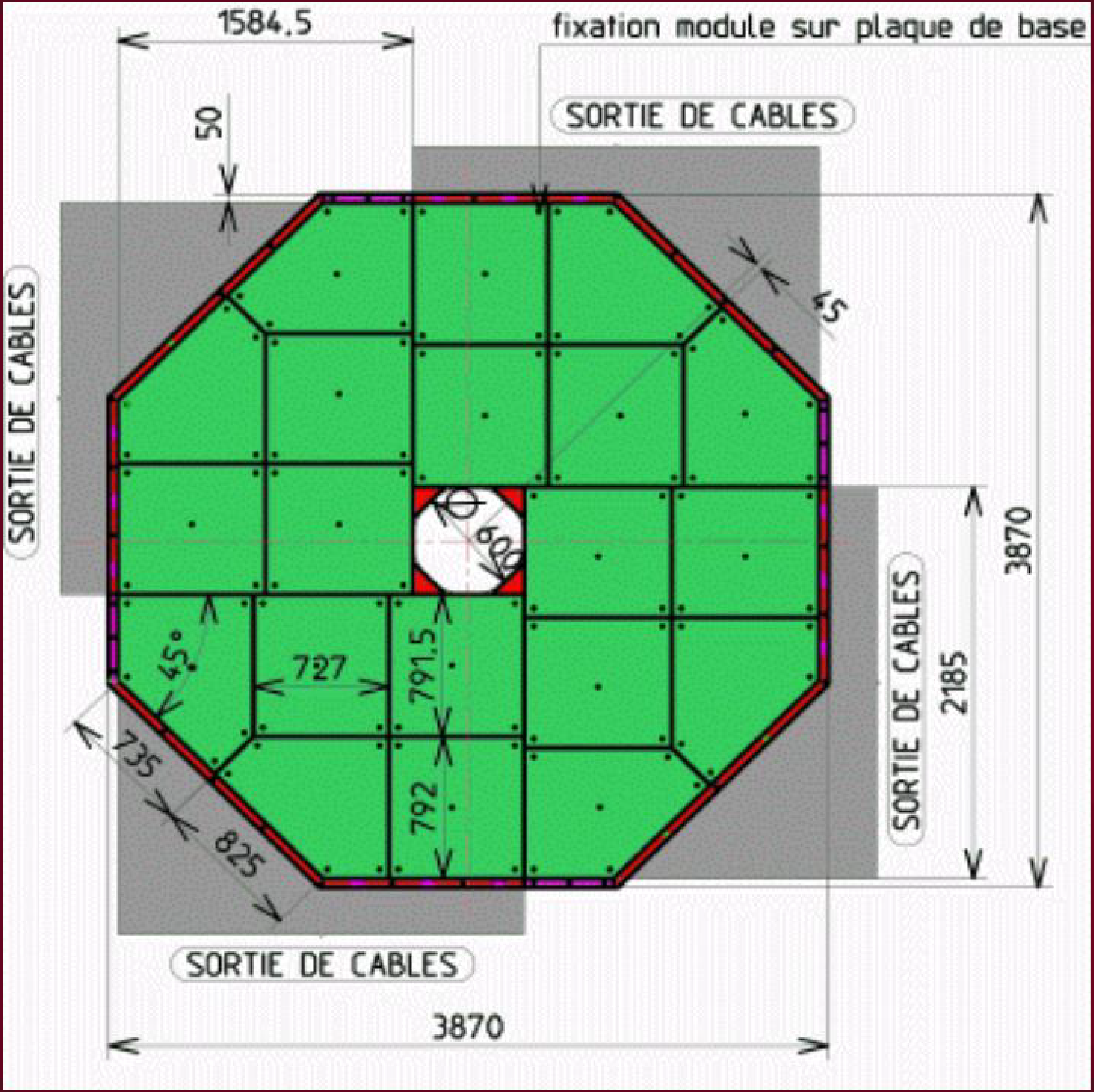
L.P.N.H.E.
Le: 20/04/2000



TESLA

The end caps



ECAL Summary

(current ideas)

40 layers of tungsten silicon sandwich

30 layers 0.4 X_0 thick

10 layers 1.2 X_0 thick

20 cm total

Silicon read out in 1x1 cm^2 pads

About 32 millions channels

Front-end difficult

Tiny space for front-end electronics

Small occupancy $<$ 30 thousand channels

Acquisition easy

The main problems, constraints

How to make a thin, efficient Si layer.

Seeing the MiP, noise, (0.1 mip) dynamics, 14-15 bits.

How to get the signals out of the detector

How to integrate in a small space a huge number of channels.

No trigger

How to industrialize the process to get quality, delays and cost.

What is expensive is basically the surface of Si.

And calibration, large number of cells, good or bad?

Si layer:

A tungsten slab (90x1.4) supports two layers of silicon
in wafers 8x8 cells
glued to the tungsten on one side
connected to the polarisation voltage through a a-Si resistor
to the read out by a capacitance a-SiN

Getting the signals out:

Flat cables made of tungsten wires 50µ at a pitch of 300.

Lrage number but small occupancy

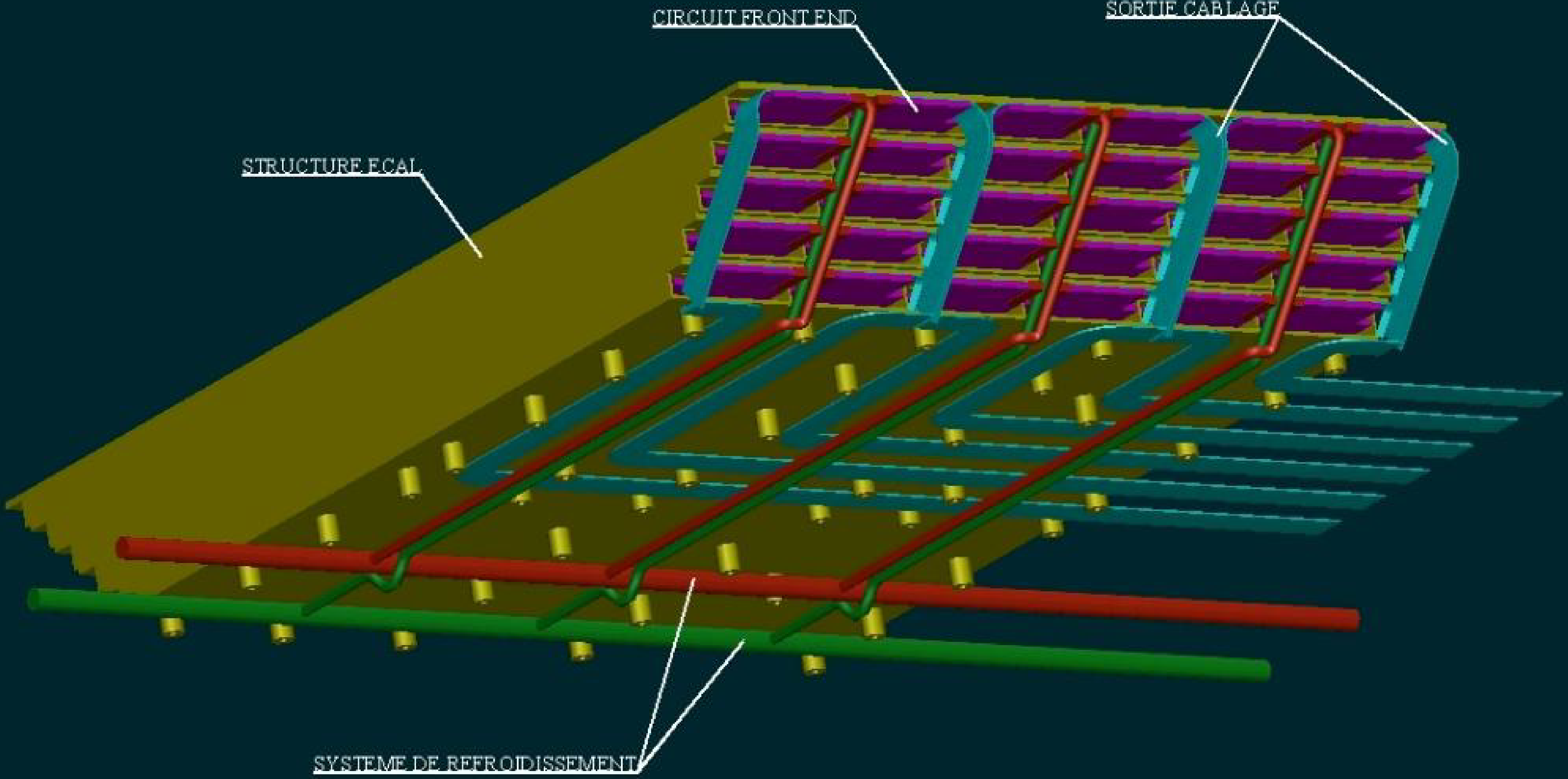
Front-end electronics:

One chip for 128 channels with two gains for the dynamics,
a threshold to cut around 1/2 mip
an analog storage for up to 100 cells with time-space address
read-out through, may be, a token ring by zones.

This is placed between ECAL and HCAL. From then on about 700 lines and ADC's to DAQ.

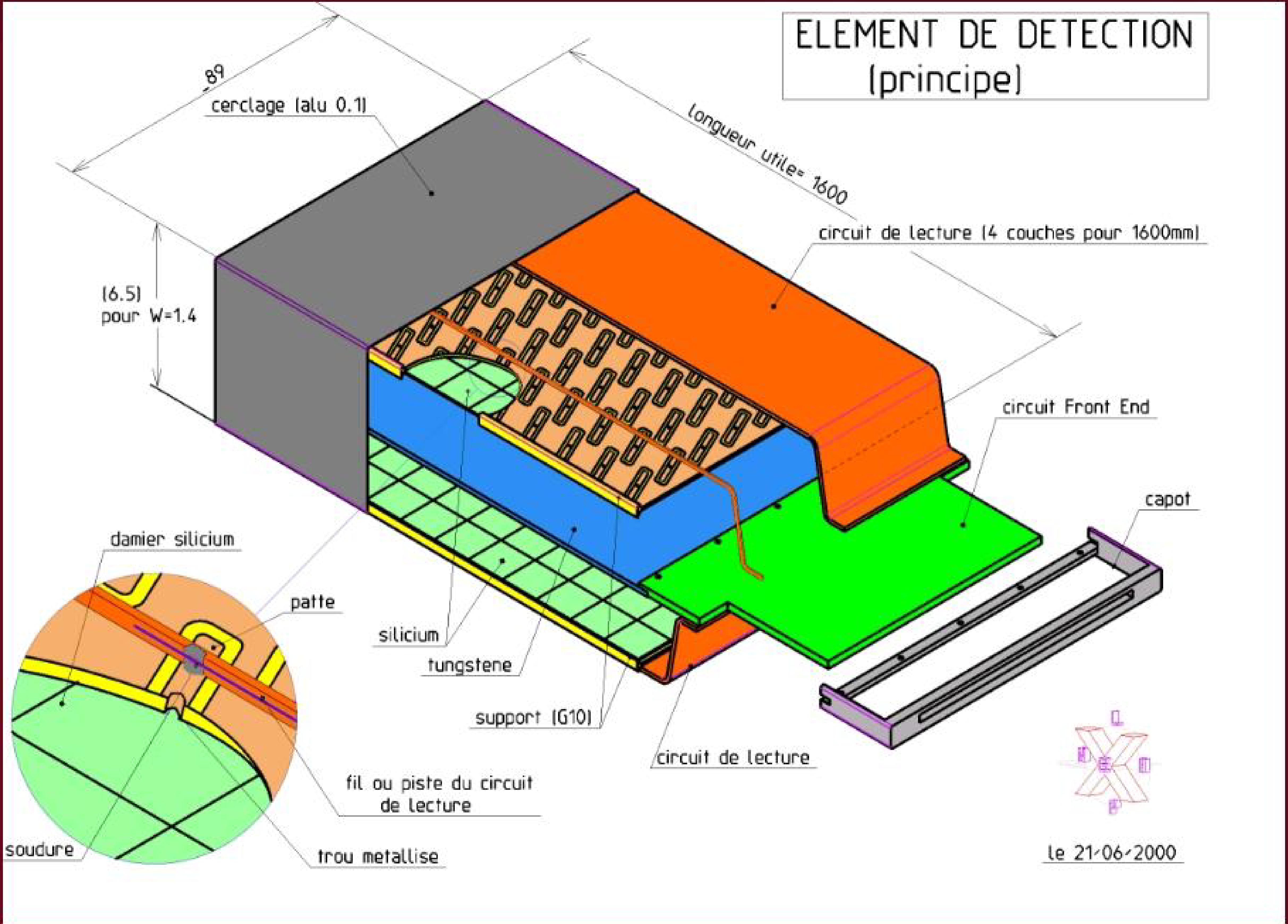
You put the events together by soft.

PRINCIPE DE SORTIE CABLAGE + REFROIDISSEMENT



ECOLE POLYTECHNIQUE

LE 14.09/2000


ELEMENT DE DETECTION
(principe)
89
cerclage (alu 0.1)
longueur utile= 1600
circuit de lecture (4 couches pour 1600mm)
(6.5)
pour W=1.4
circuit Front End
capot
damier silicium
patte
silicium
tungstene
support (G10)
circuit de lecture
fil ou piste du circuit
de lecture
soudure
trou metallise
le 21/06/2000

A glimpse at the hadronic part

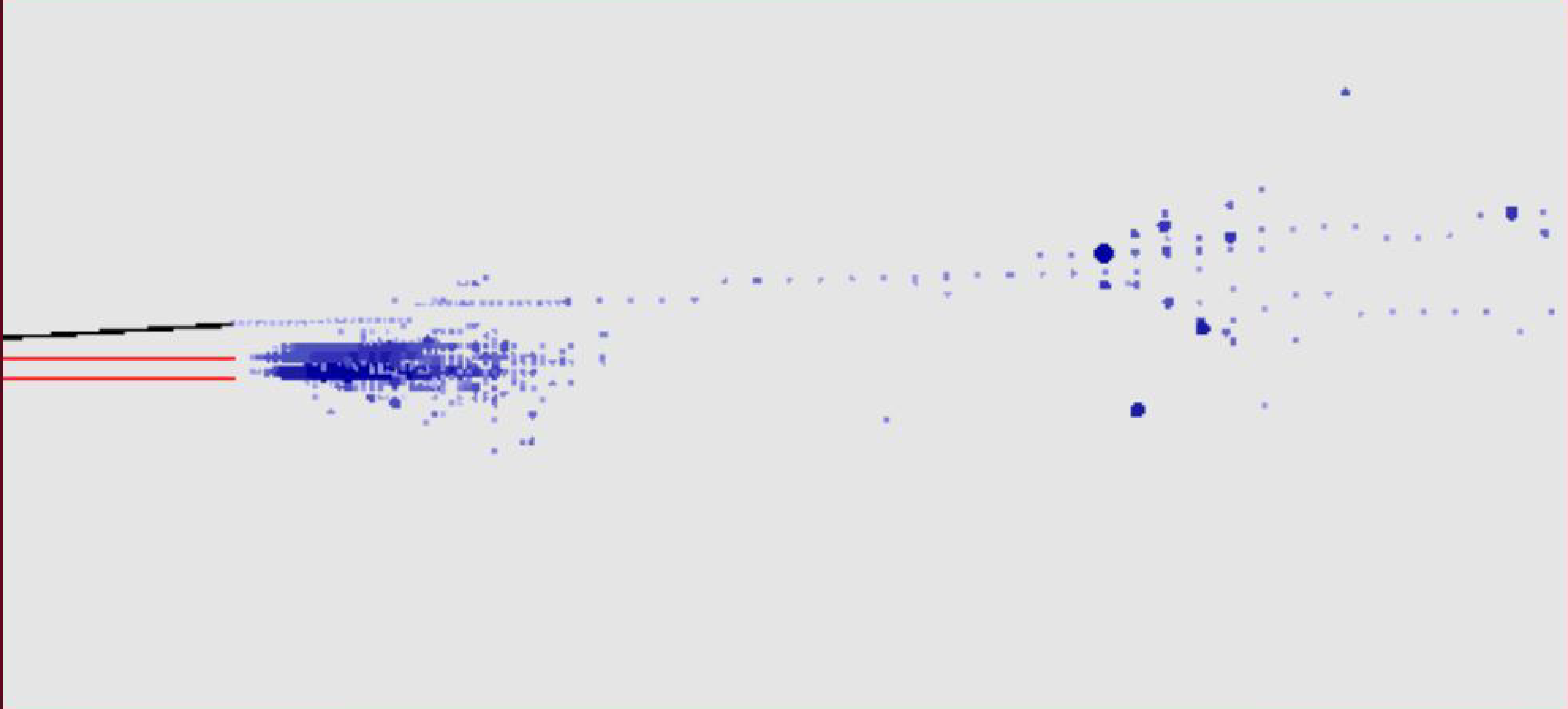
A stainless steel radiator

A detector providing a digital signal from small cells

Streamer or Geiger cells
or RPC‘s read by shift registers

The resolution obtained that way compares well
with an analog detection, excellent pattern.

From simulation and ALEPH



300 GeV $\tau \rightarrow \nu_\tau \rho$

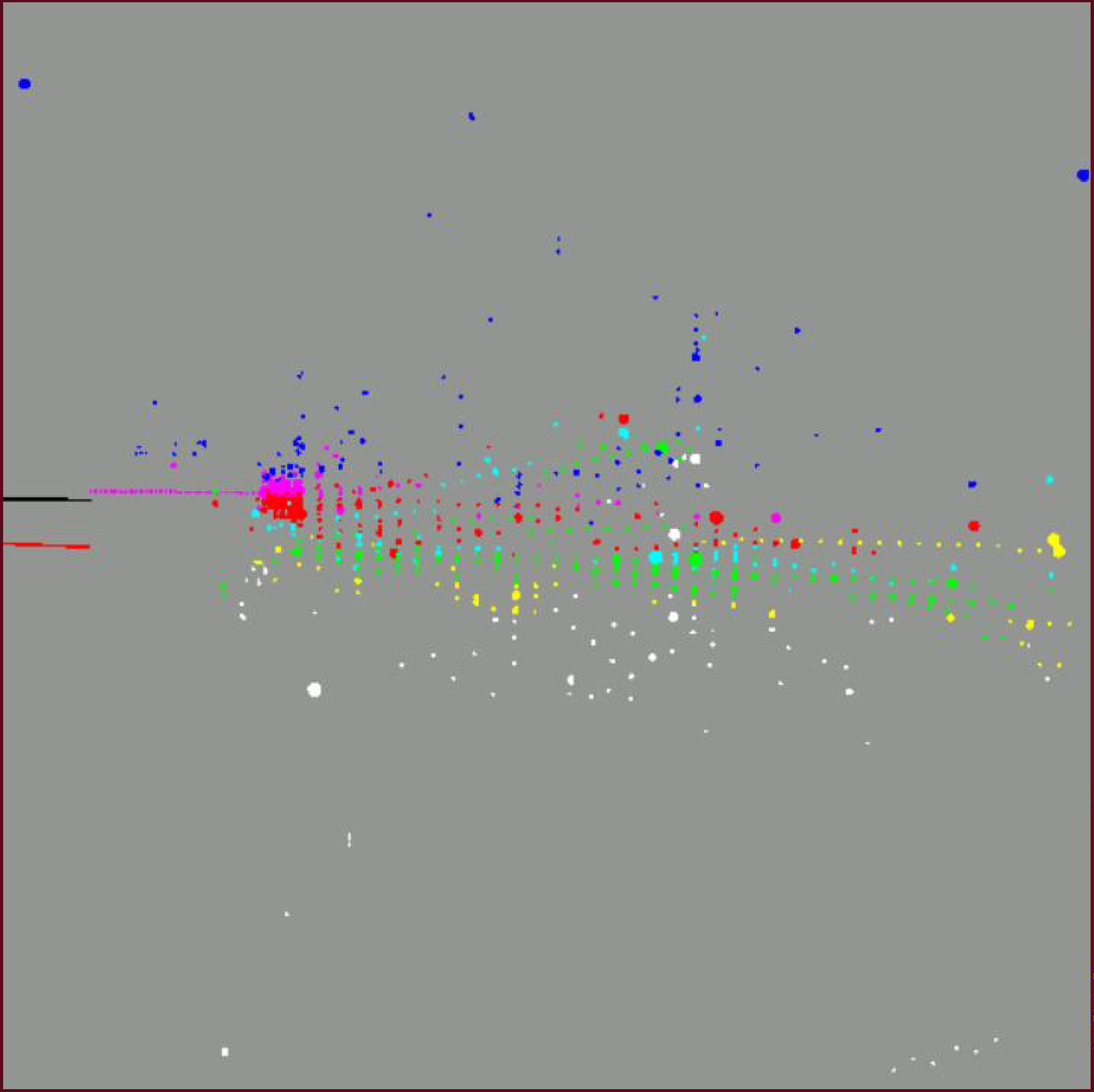
$\rho \rightarrow \pi^{\pm} \pi^{0}$

TESLA

A high granularity ECAL and HCAL

Cell size 1x1x0.5 cm^3

Back to bubble chambers?

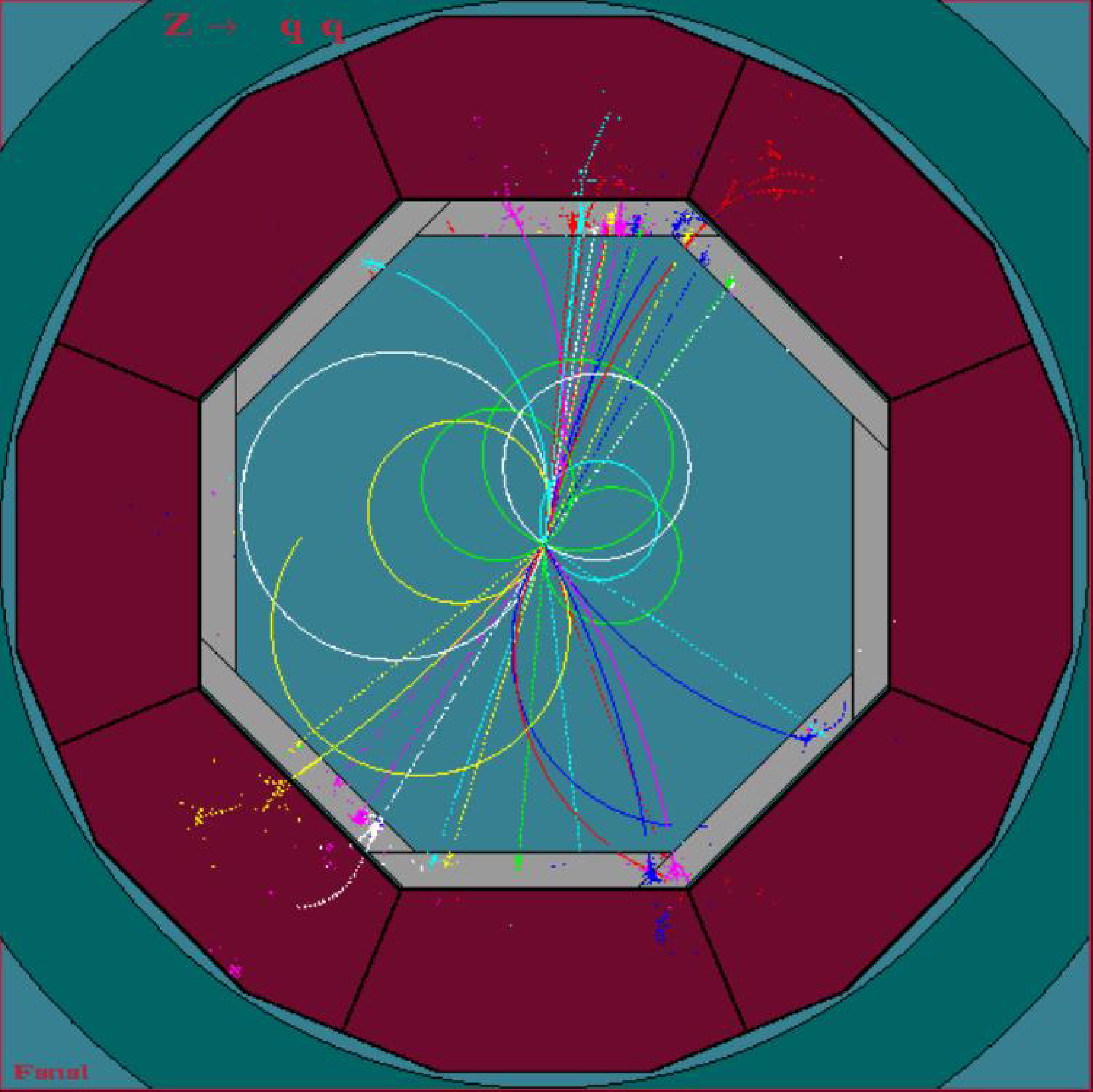


TESLA

300 GeV $\tau \rightarrow \nu_\tau K^*$

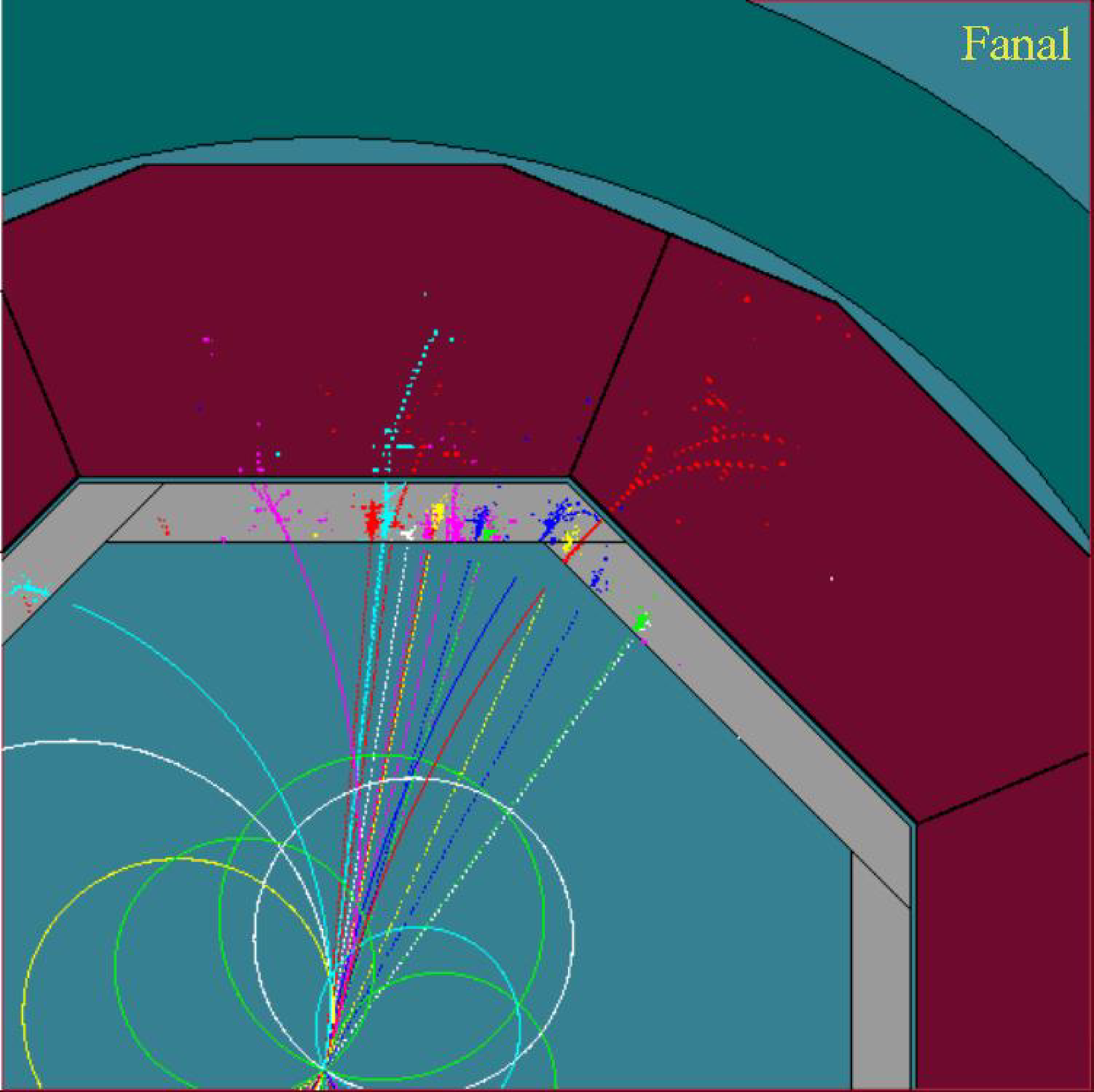
$K^* \rightarrow \pi^\pm K_l$

The depth is coded by colour
The energy by the bubble size



$Z \rightarrow q\bar{q}$

Fanal



$Z \rightarrow q\bar{q}$

Performances

From a Geant4 study

Photon efficiency
Rate of fakes / distance

Neutral hadron efficiency
Rate of fakes

Energy resolution (ECAL) $0.12 / \sqrt{E}$ ≈ Flat with angle

Position resolution $1 / \sqrt{E} + 0.4$ mm

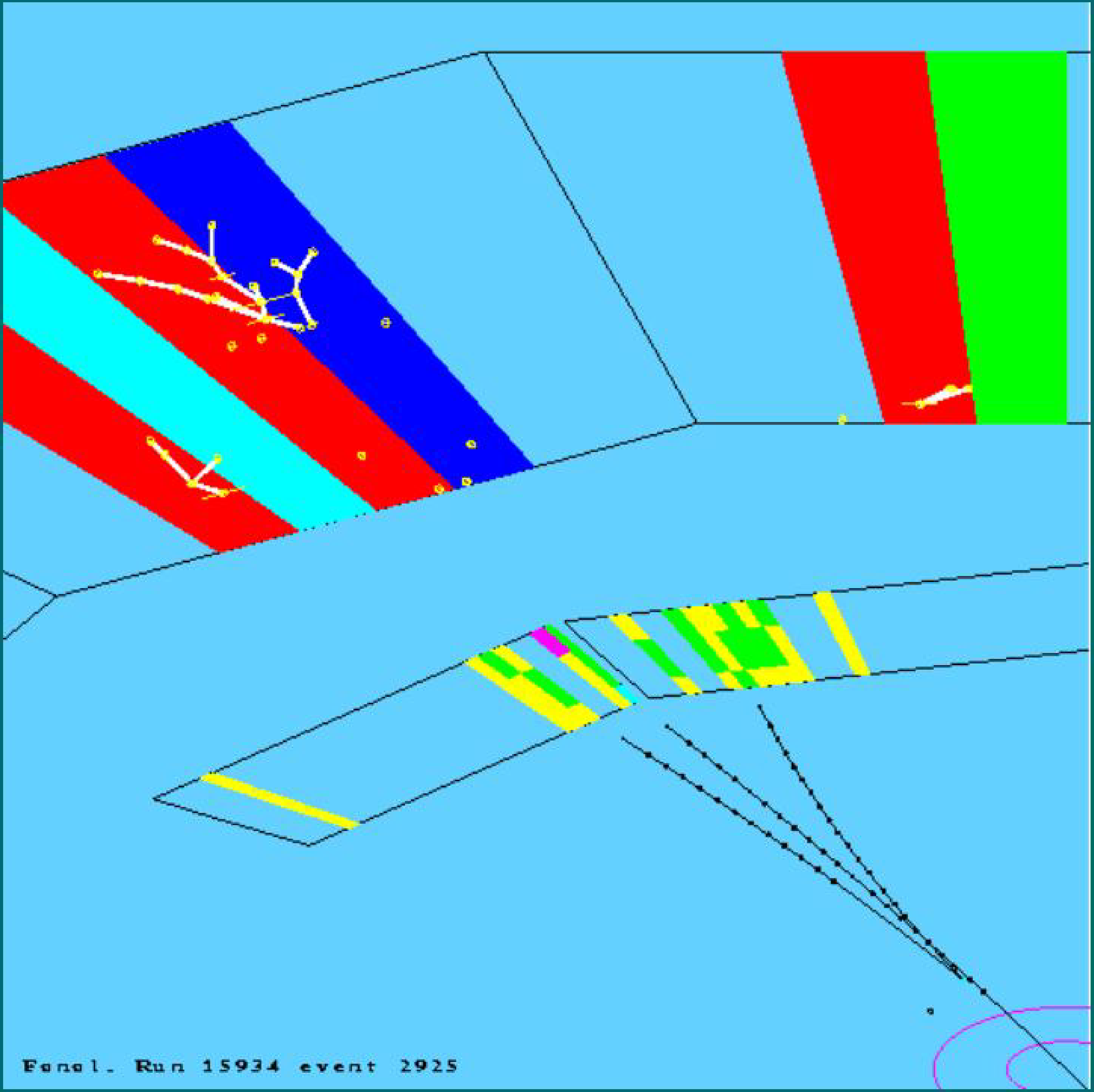
Angular resolution $60 / \sqrt{E}$ mrad

Jet visible energy resolution $0.20 / \sqrt{E}$ tracks + γ's

$0.37 / \sqrt{E}$ all

Mass resolution 2 times better than ALEPH

Muon and electron identification



ALEPH

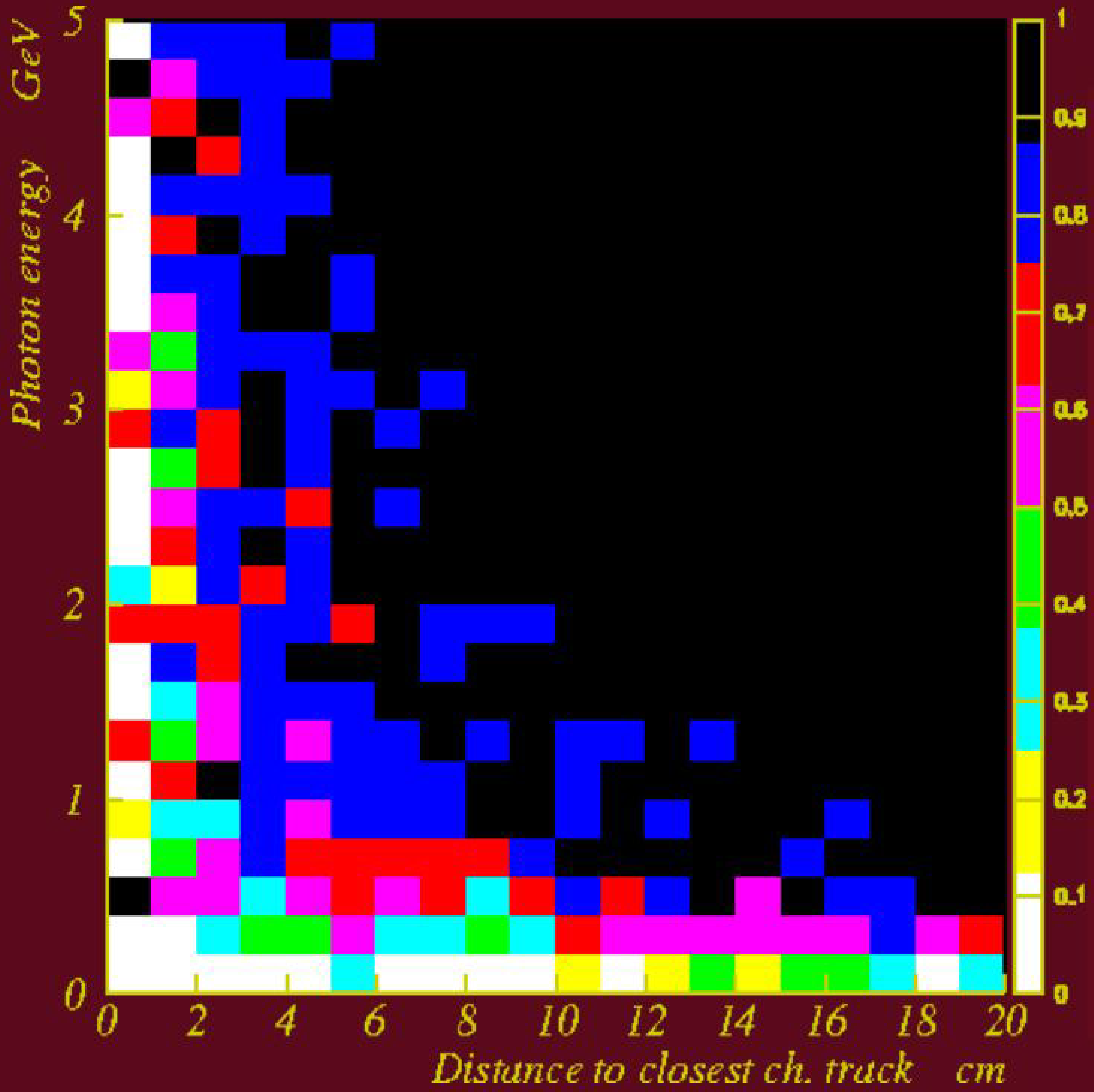
$\tau \rightarrow \nu_\tau \, \pi \, K_s \, K_l$

The HCAL is made of streamer tubes read-out in towers analogically, by tubes digitally.

The K_l is clearly seen as an interaction in the digital pattern.

The resolution from the bidimensional digital counting is equivalent to that from the analog read-out.

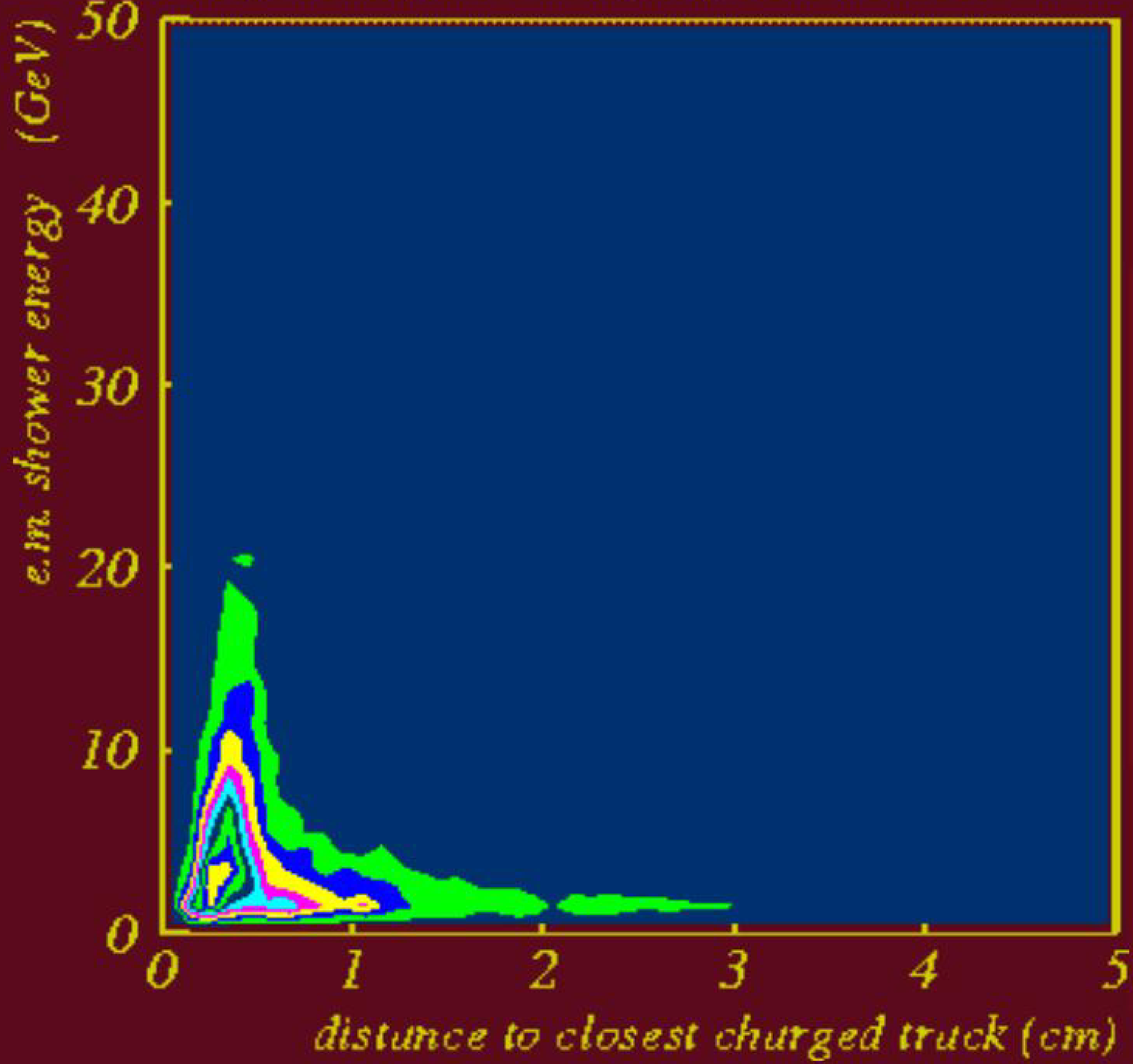
Not only do we loose energy in the coil but als the connection between ECAL and HCAL.



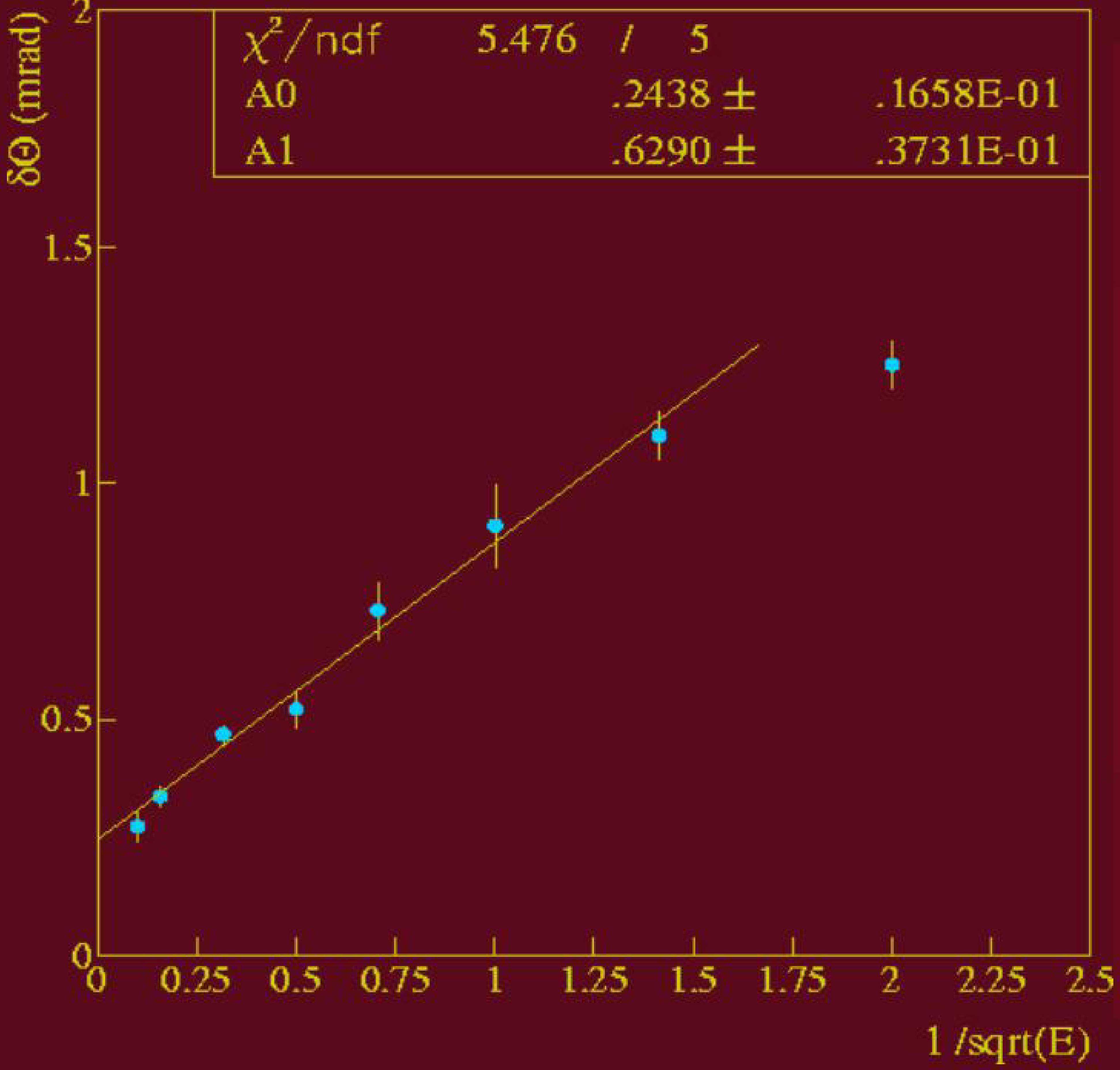
Photon efficiency
as a function of
- distance to closest
charge track
- photon energy

In fact p_T

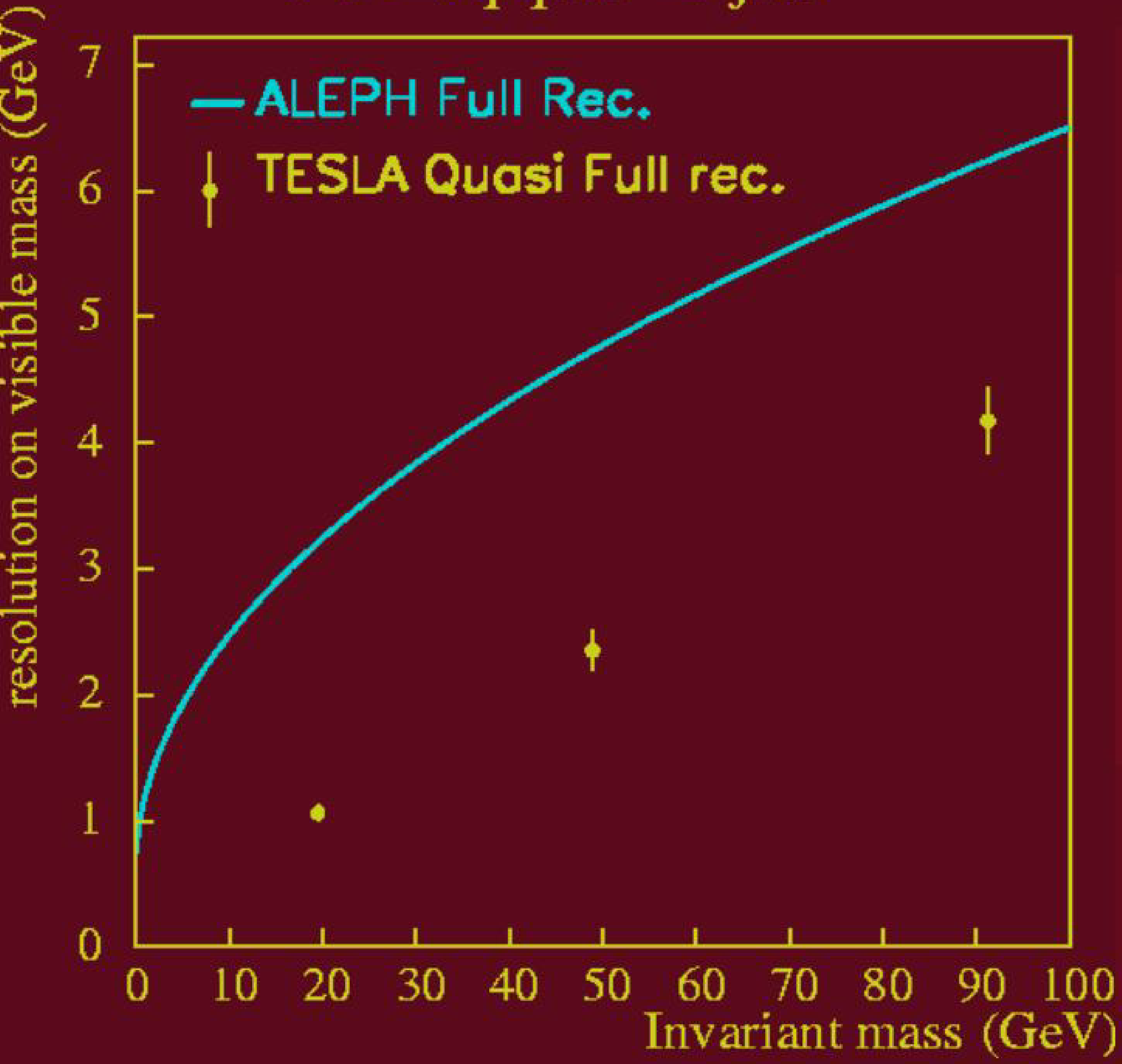
Fake photon from charged pion interaction

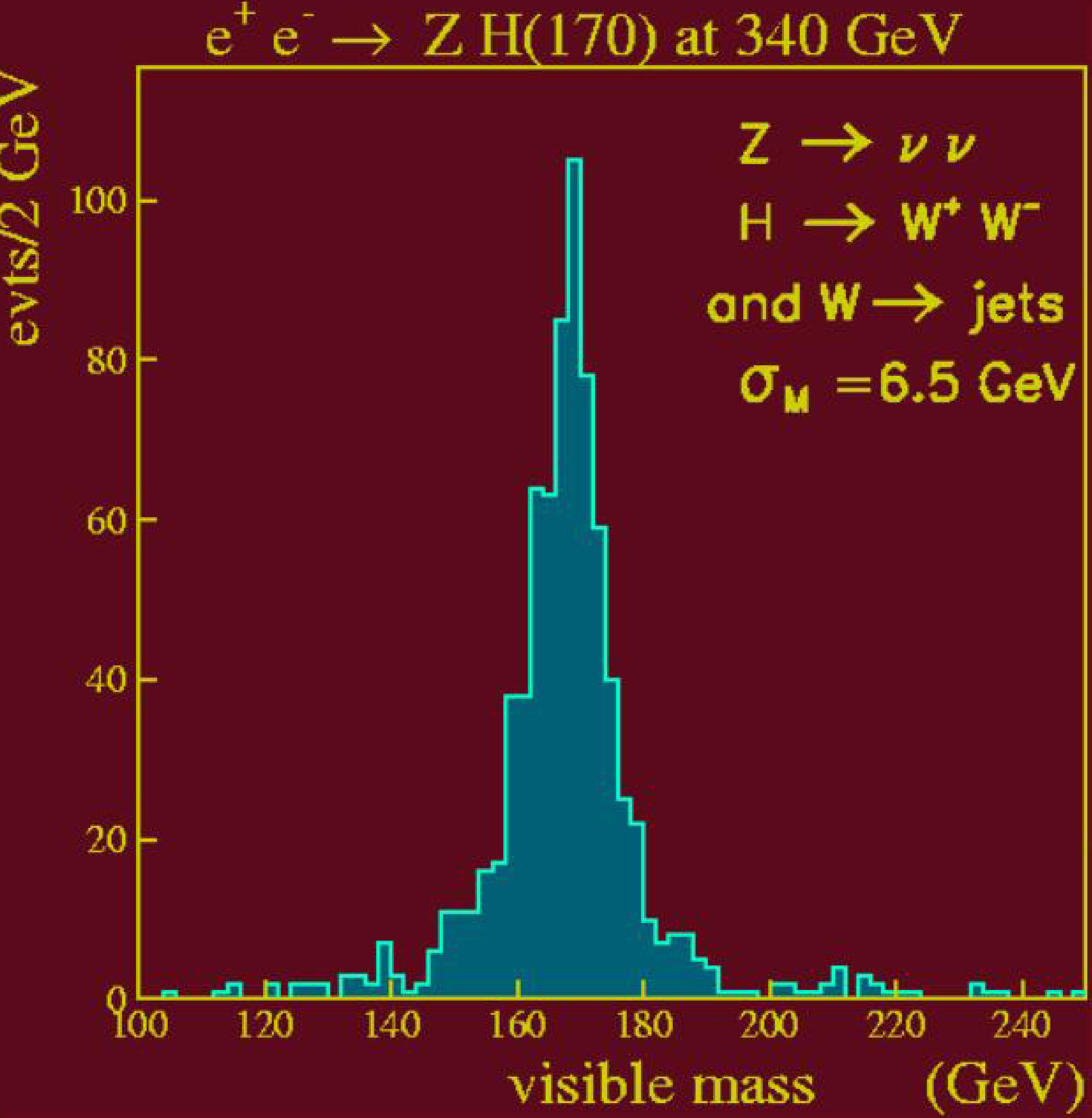


PHOTON simulated with GEANT4 and MOKKA



$e^+e^- \rightarrow$ q qbar $\rightarrow$ jets




$e^+ e^- \rightarrow Z\,H(170)$ at 340 GeV
$Z \rightarrow \nu\,\nu$
$H \rightarrow W^+ W^-$
and $W \rightarrow$ jets
$\sigma_M = 6.5$ GeV
evts/2 GeV
0
20
40
60
80
100
120
140
160
180
200
220
240
visible mass (GeV)

Conclusions

A very hermetic and granular calorimeter optimal for Higgs physics at an electron linear collider seems technically feasible even though some items remain quite challenging.

Aside the hardware design, the software for exploiting the remarkable pattern capabilities of such a pictorial calorimeter is a new challenge.

And it may bring a lot of unexpected goodies.

Calorimetry is not simply the art of getting the best energy resolution

It appears even that the actual hardware energy resolution is secondary when we are not in the school case of an isolated particle.

3d pictorial calorimeters are a new field and reserve probably some good surprises since up to now we do not have any proper analysis tool to exploit all the shape information they provide.

Calorimetry:
An art of compromise