"Energy flow or particle flow"

or

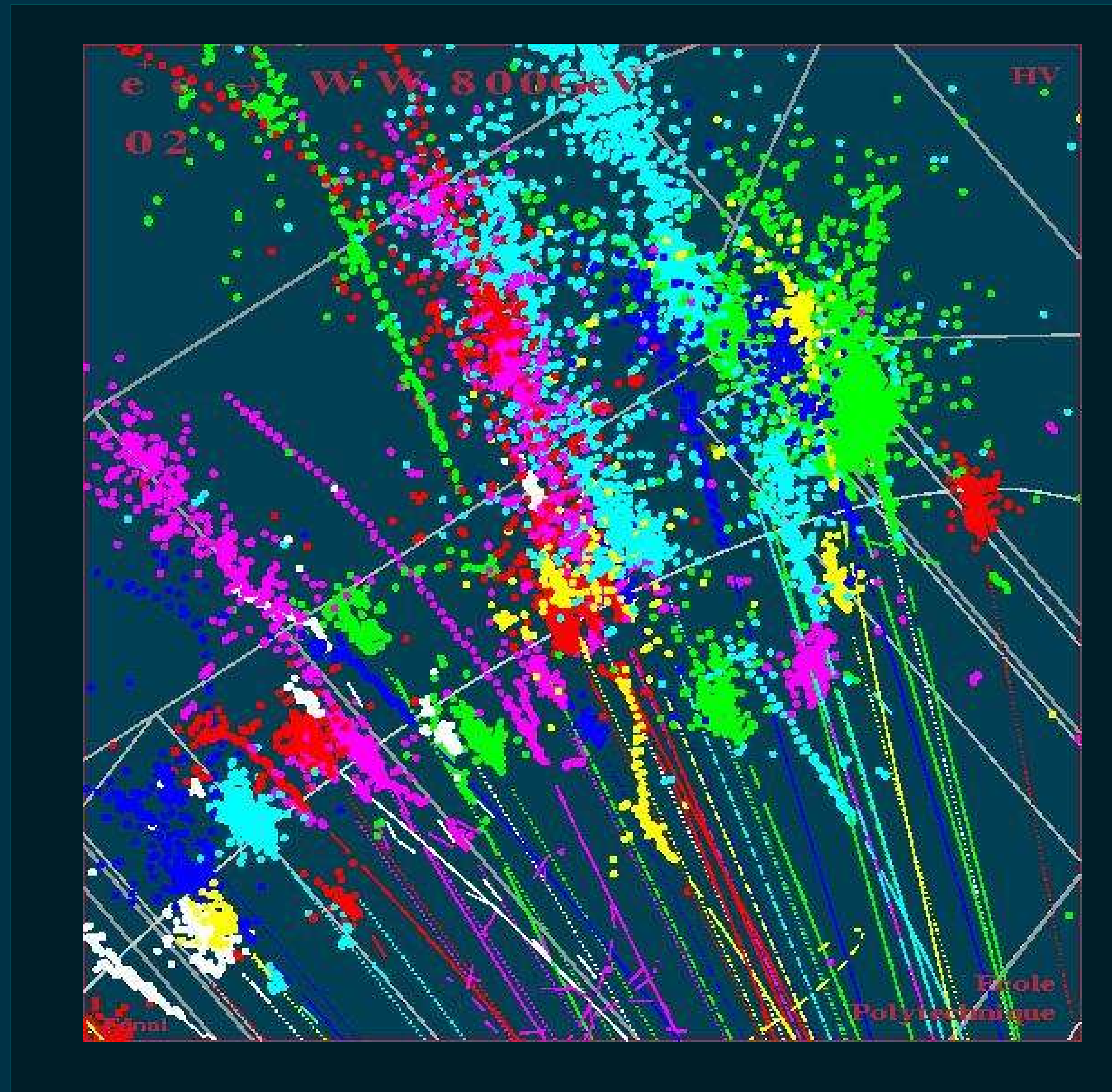
How to extract a maximum of information from an event

The technique of "energy flow"

for pedestrians

Everything you always wanted to know about "energy flow" but were afraid to ask

Flowers of energy



The energy
of
the flowers

Pedestrians wandering around energy flows

We wish to extract as much physics as possible from the data we collect
all the physics

A noble purpose

For that purpose can we find a smart and inexpensive way
or
do we need to make it the painful way,
reconstructing every single piece of every event.

This second approach, limited by the detector performance,
is what we mean by "energy flow" or "particle flow" approach
even though these appellations do not sound really adequate

The physics we consider:
a cocktail of final states like

$$t\,\bar{t} \quad b\,W^{+}\;\bar{b}\,W^{-}$$

$$t\,\bar{t}\,H$$

$$Z\,H$$

$$Z\,H\,H$$

$$\nu\,\bar{\nu}\,W^{+}\;W^{-}$$

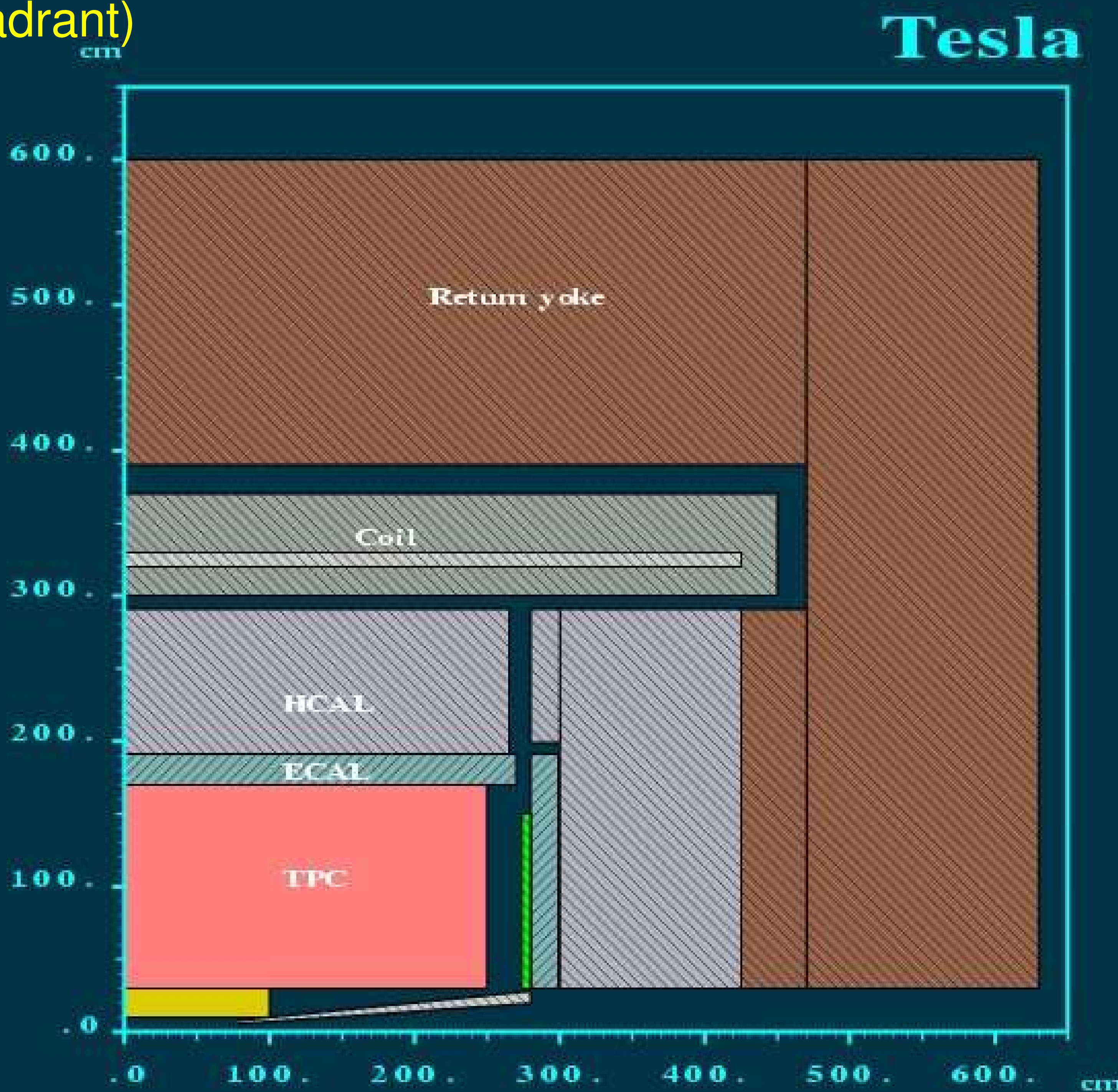
and many others, stop pairs, ...

most often we want just to see Z, W or H bosons
as "standard particles"

while they decay in leptons, including neutrinos, and jets

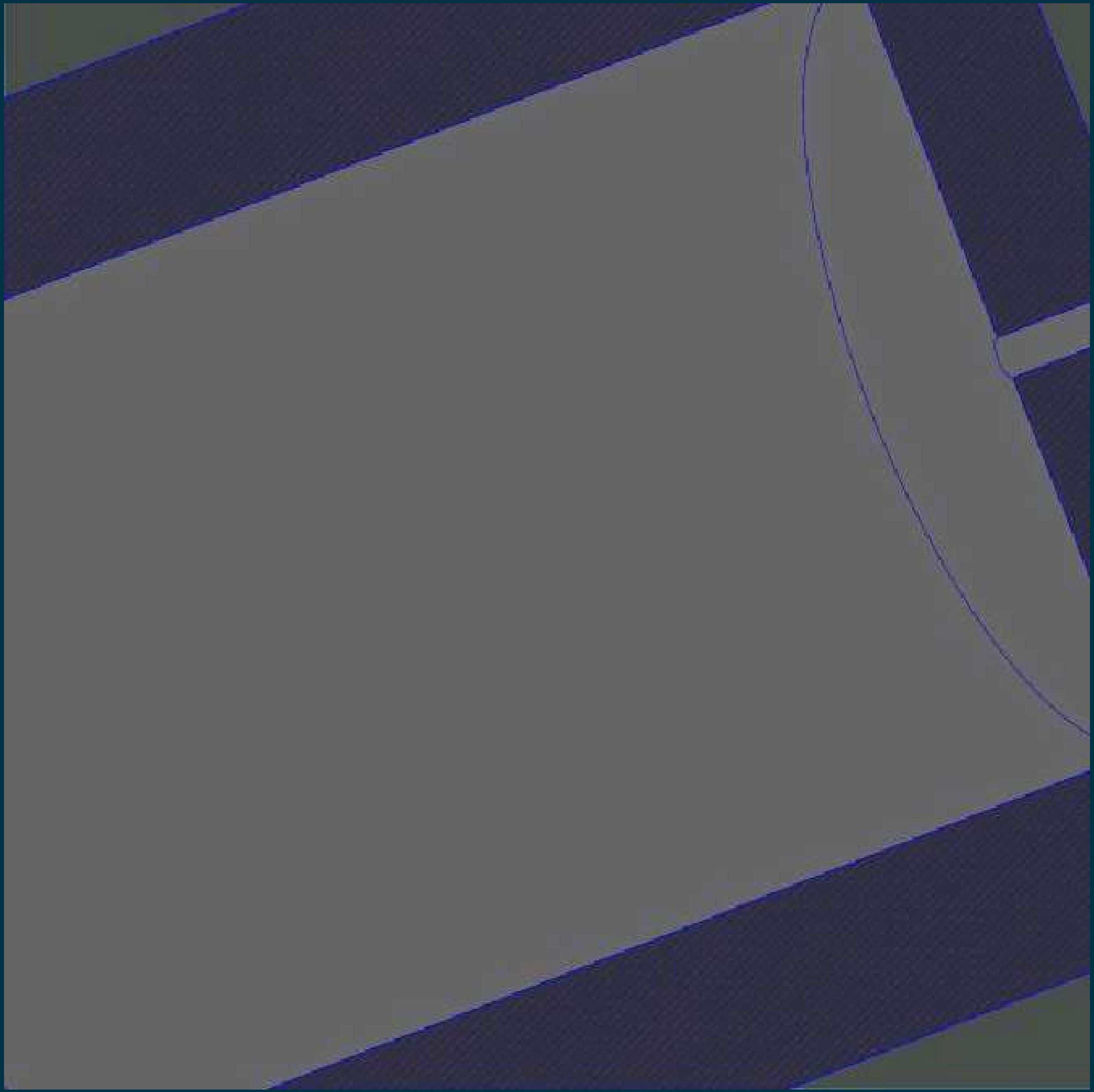
in detectors like →

Detector cut (quadrant)



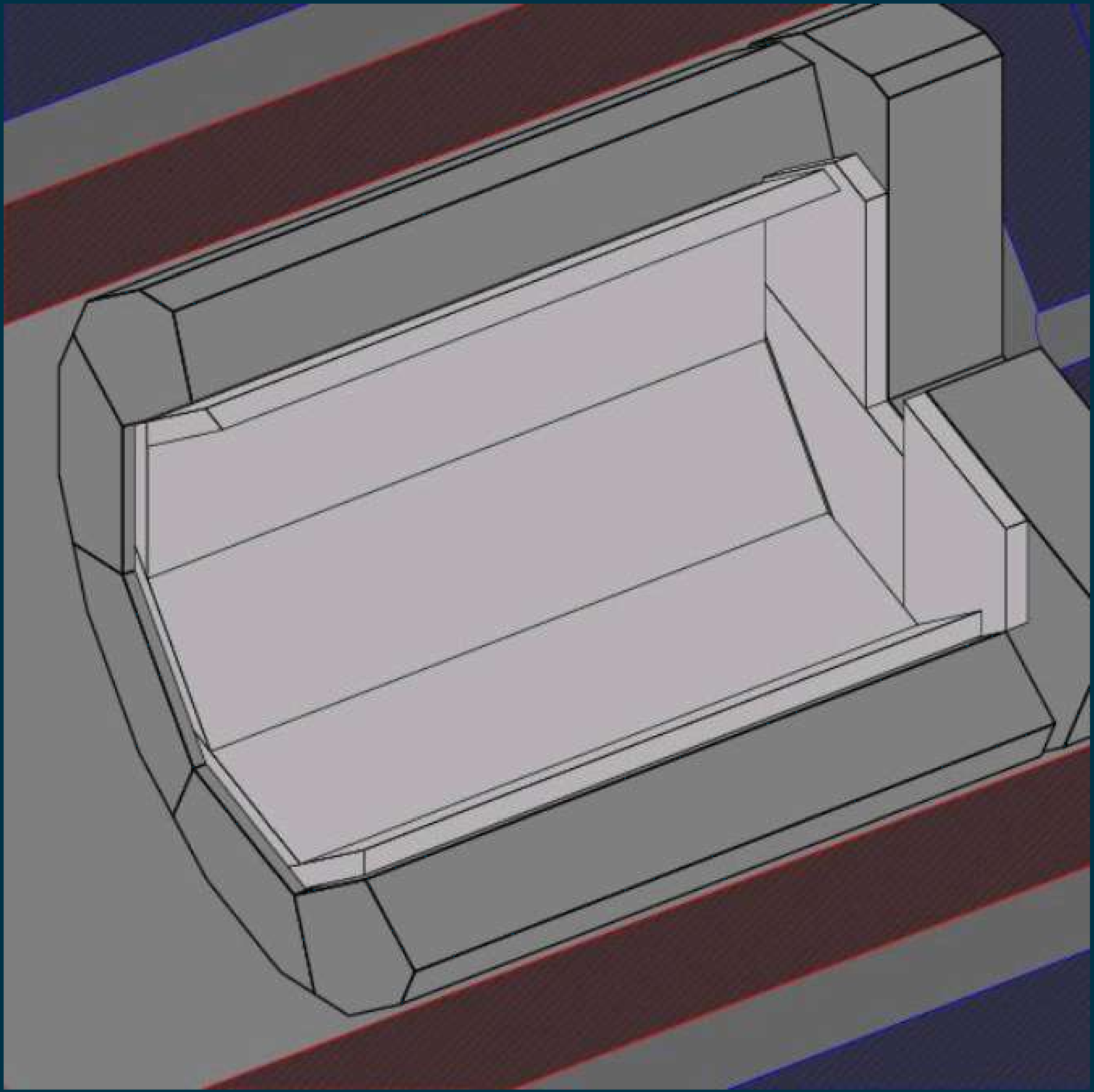
Putting in place the calorimeter shells

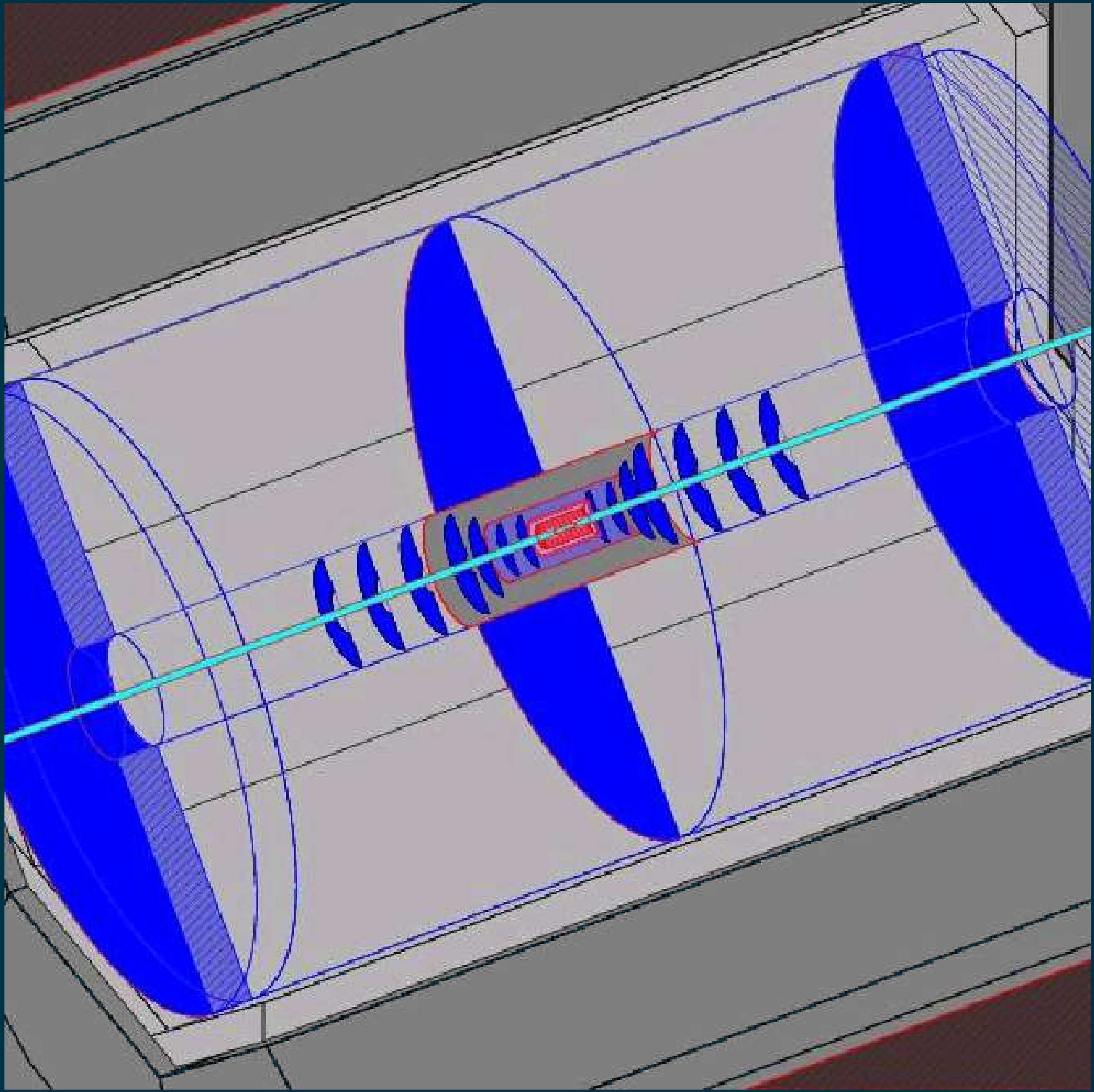
Return yoke and
muon detectors
Coil 4T
Pole tip
Hcal end cap
Hcal barrel
Ecal end cap
Ecal barrel



Track detetectors

- Forward chambers
- TPC
- SIT
- Forward disks
- Vertex detector
- Beam tube



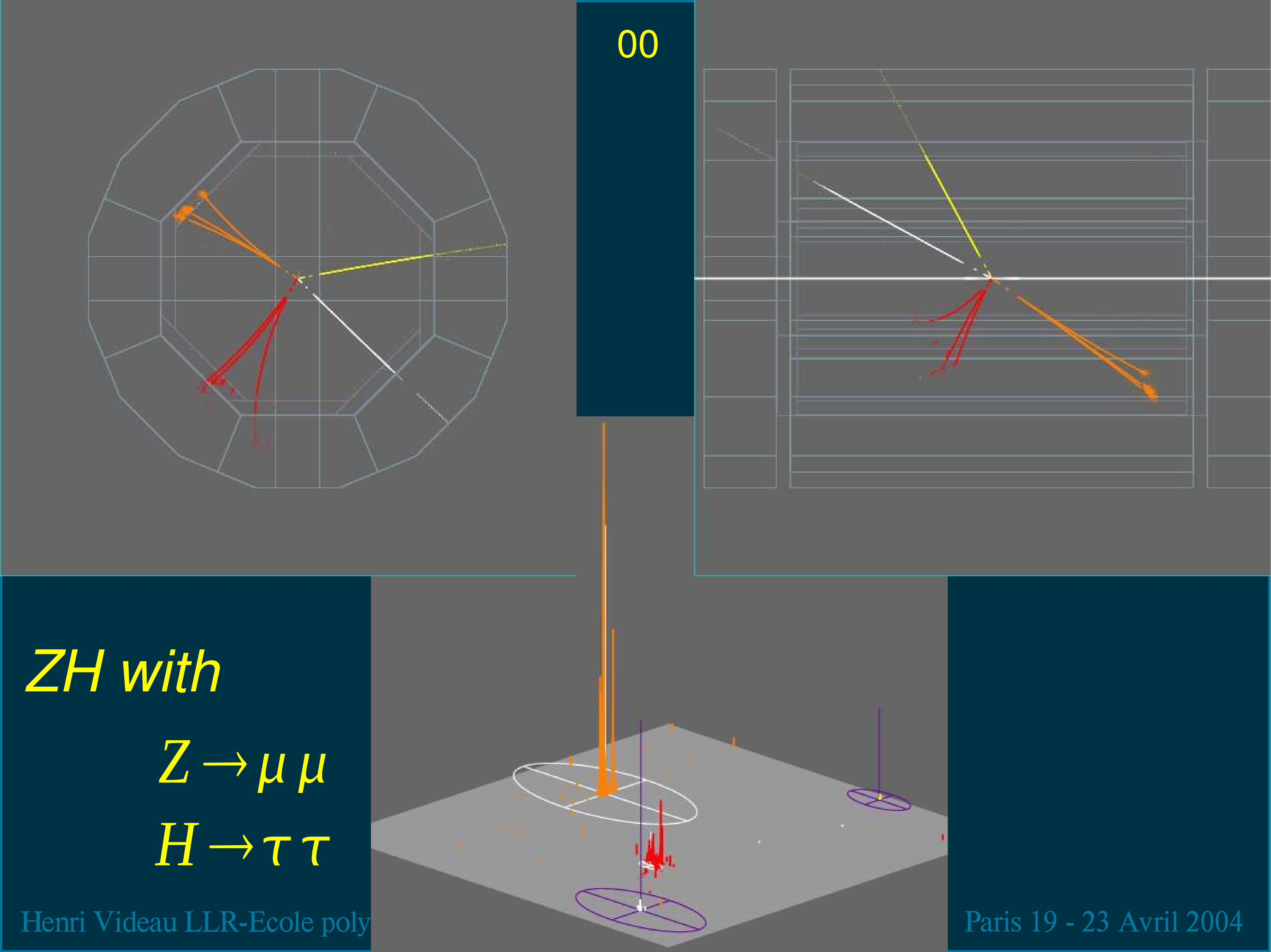


Some events look extremely clear and simple

some look very busy

Can they really be analysed globally
or do we need to disentangle every component?

Have a look



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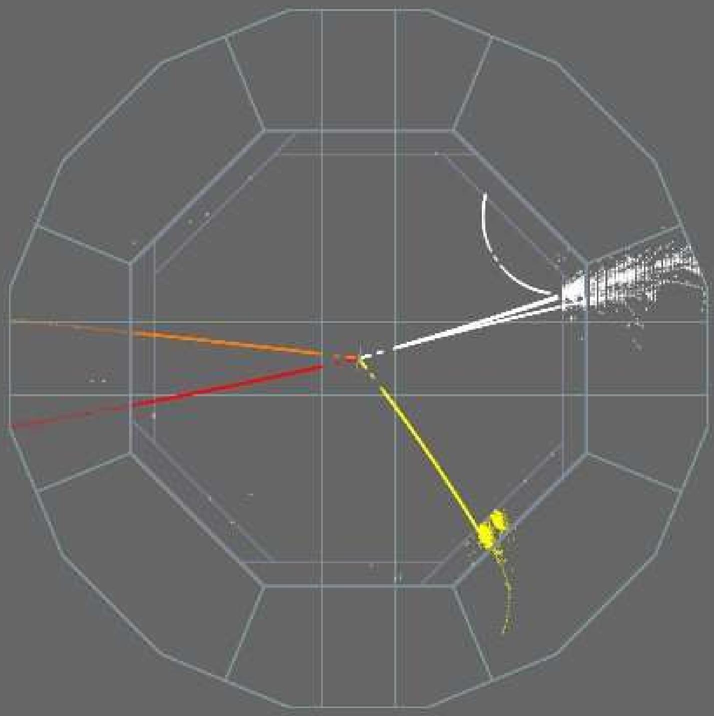
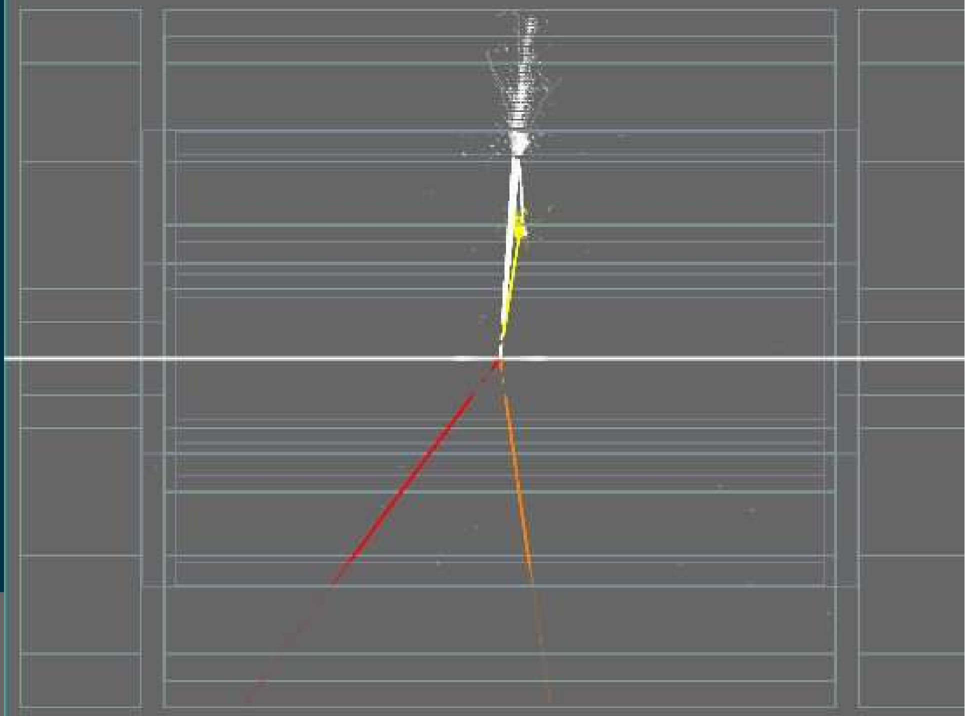
ZH with

$Z \rightarrow \mu\mu$

$H \rightarrow \tau\tau$





ZH with

$Z \rightarrow \mu\,\mu$

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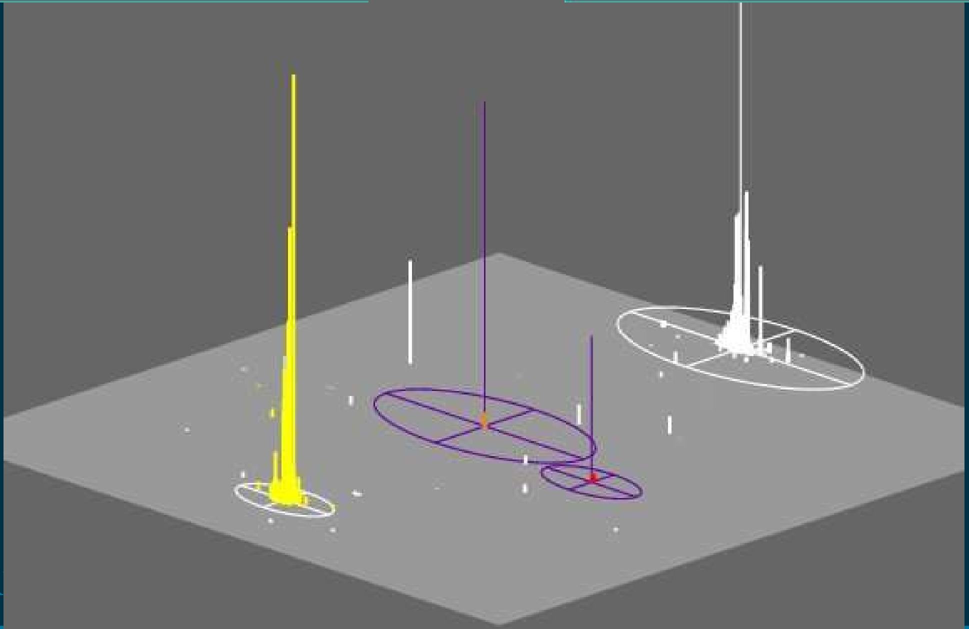
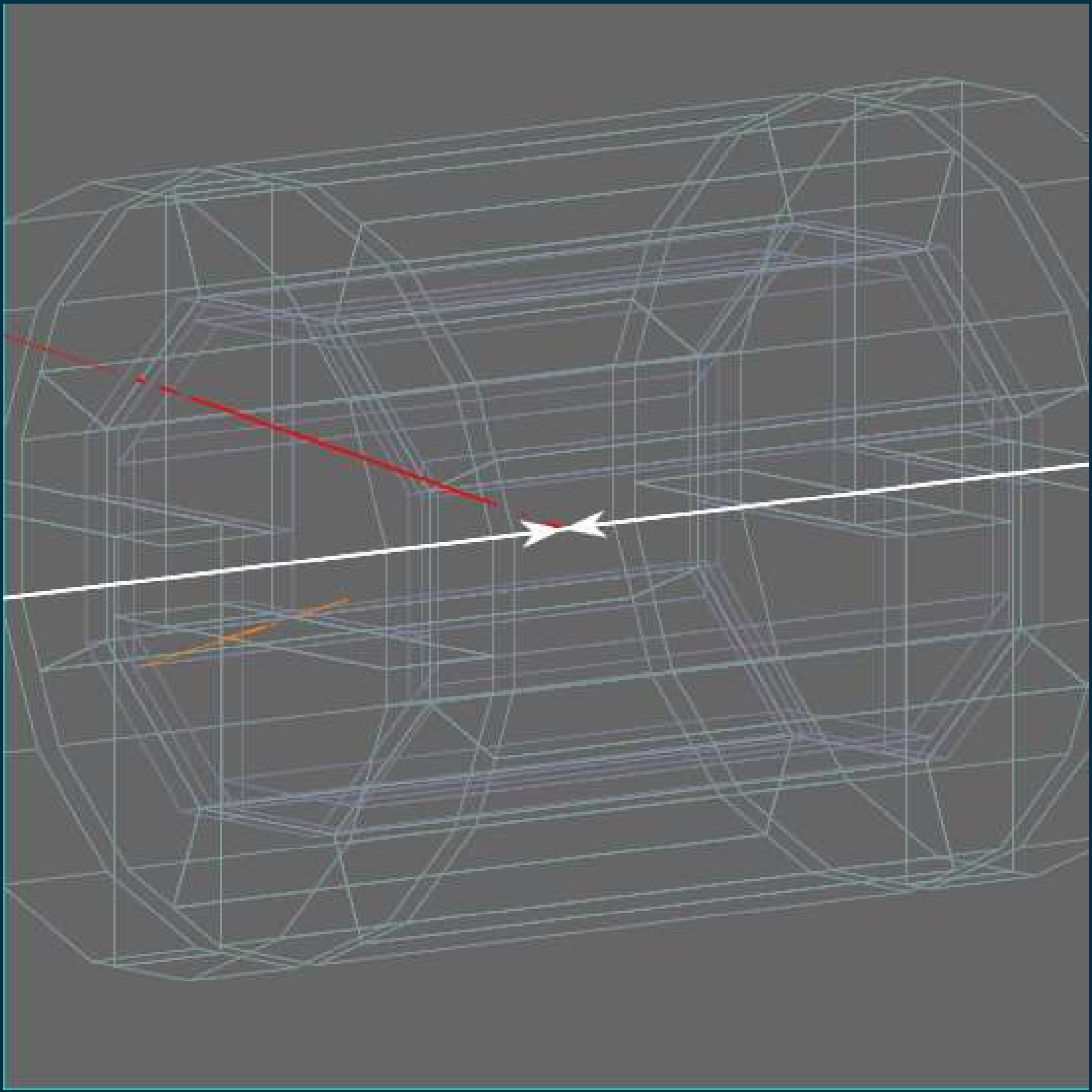


What about this one:

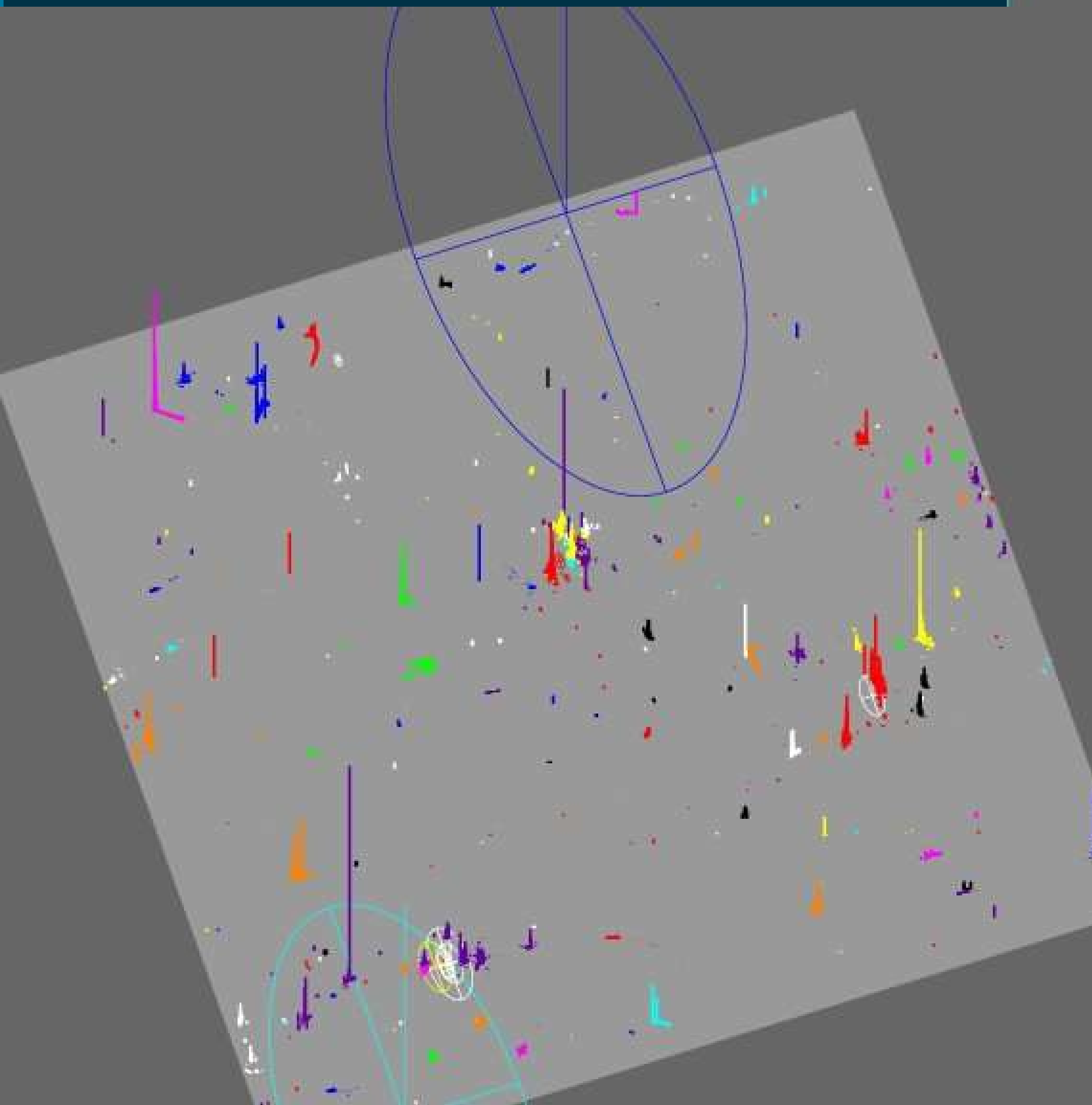
in fact $\nu \bar{\nu} Z Z$

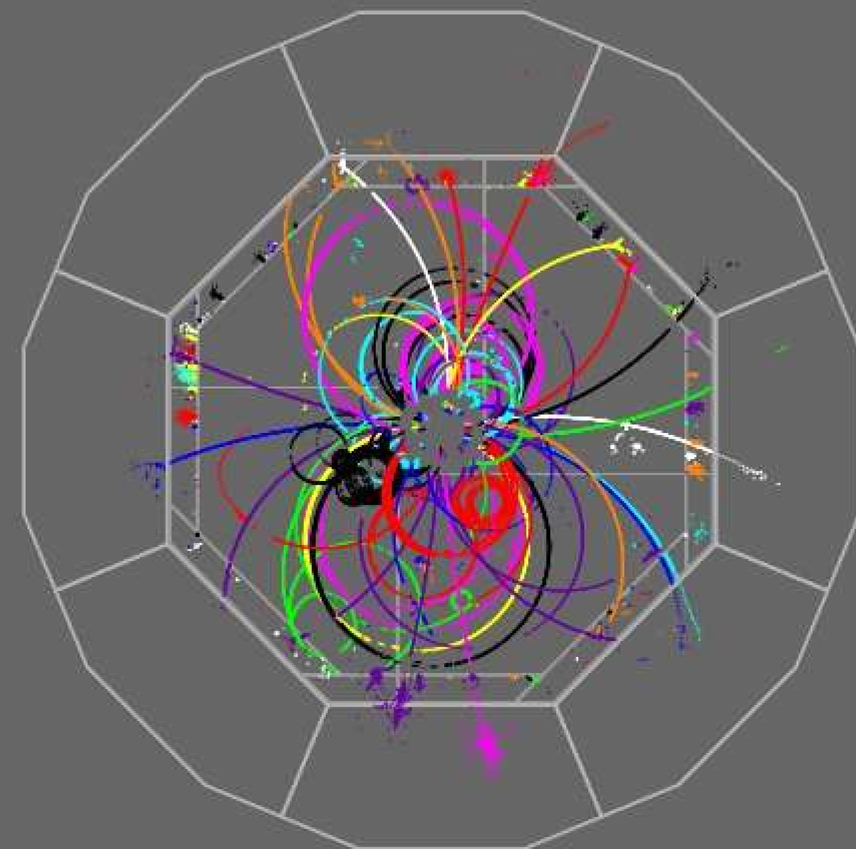
Measuring
the recoil mass



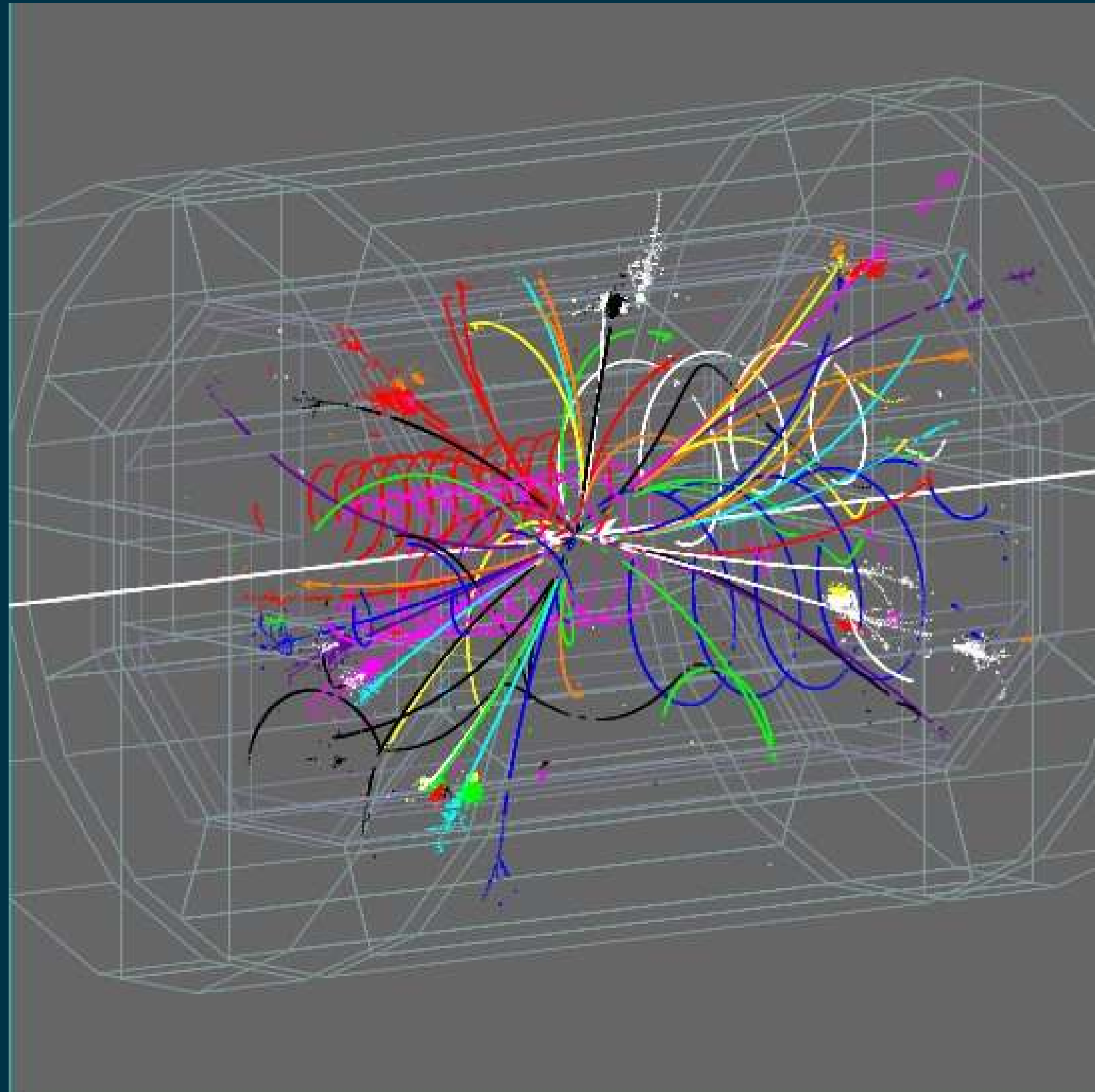
Effect of the high field

$$\nu \bar{\nu} \mathbf{Z}\,\mathbf{Z}$$



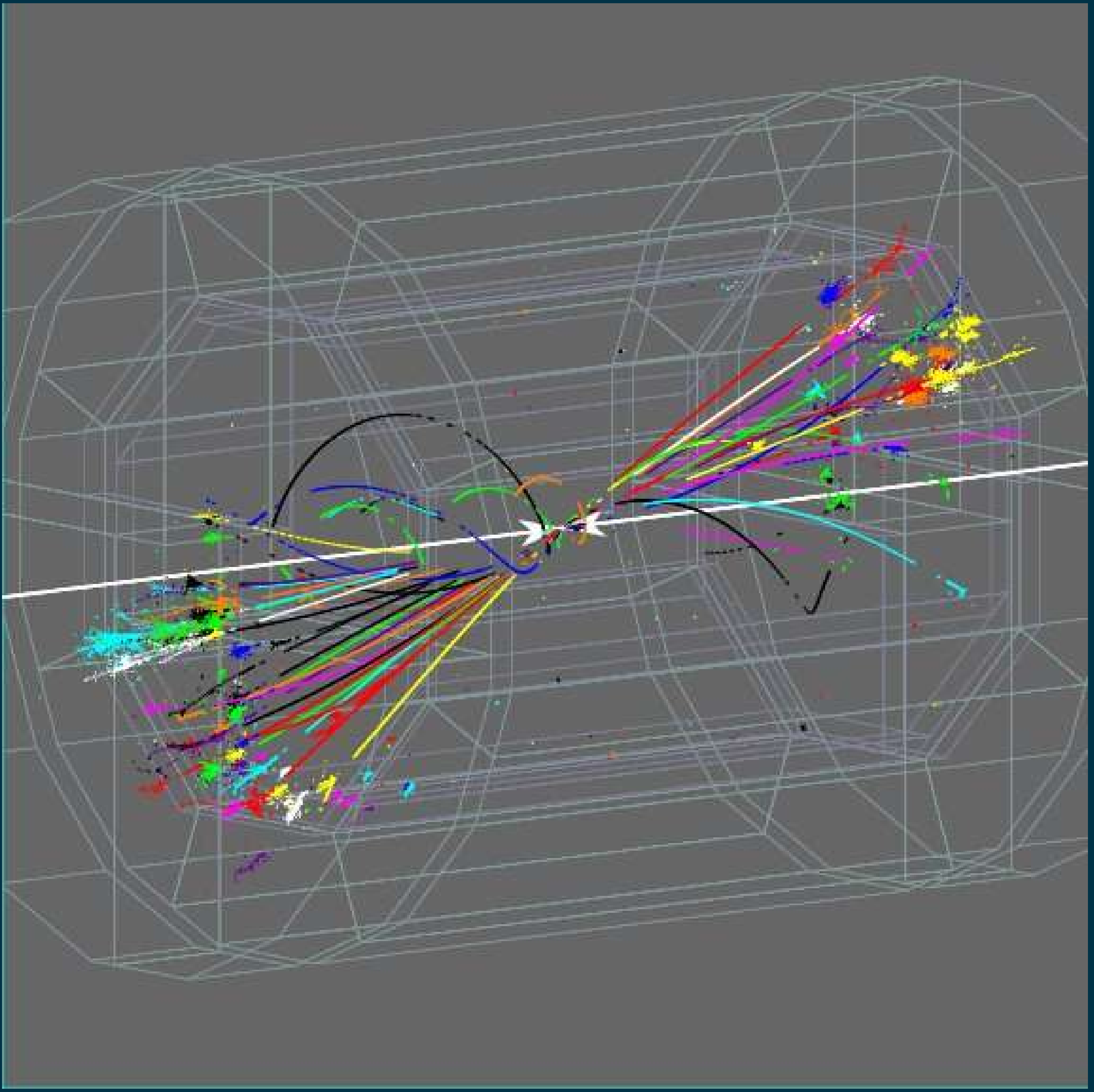


$t\,\bar{t}$



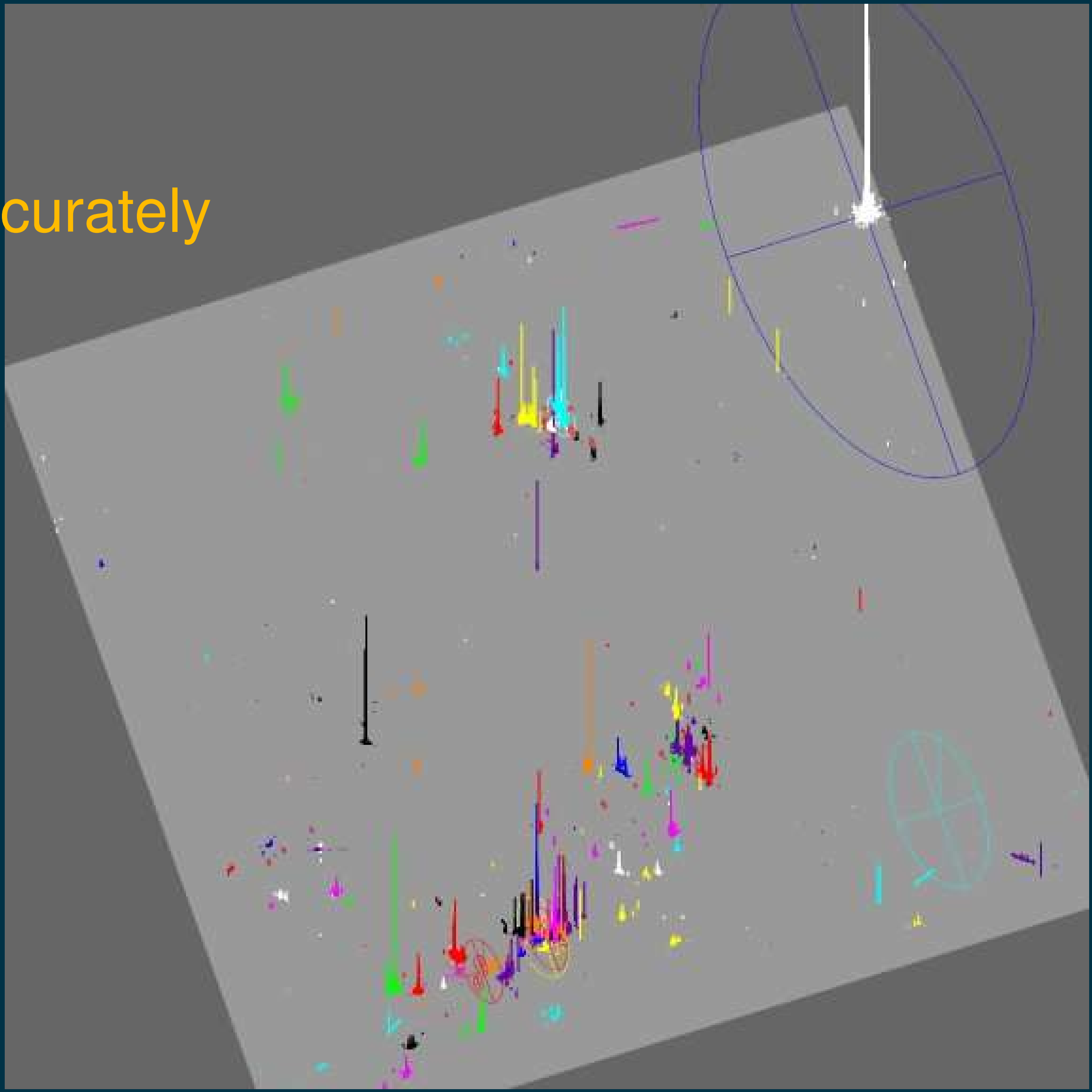
Interesting role of the end caps

The opening goes as BL^2, but at low angle count only on L



We have a large variety of events

presenting
isolated leptons which
have to be measured very accurately
jets or dijets



The particle we are dealing with are:

neutrinos: not much to be done except
know that there is one (signed by charged leptons),
may be estimate the missing P

electrons: measured by the tracker and the Ecal
problem of Bremsstrahlung and δ rays
identified by Ecal (above 1 GeV P_t), dE/dx (below)
know where they come from, conversion?
identify them in a dense environment

muons: measured by the *tracker only, with field*
identified by Hcal and muon system
identify them in dense environment

charged hadrons: measured in the tracker and Cal
identified as "no lepton"
know where they are coming from, V0' s, short decays

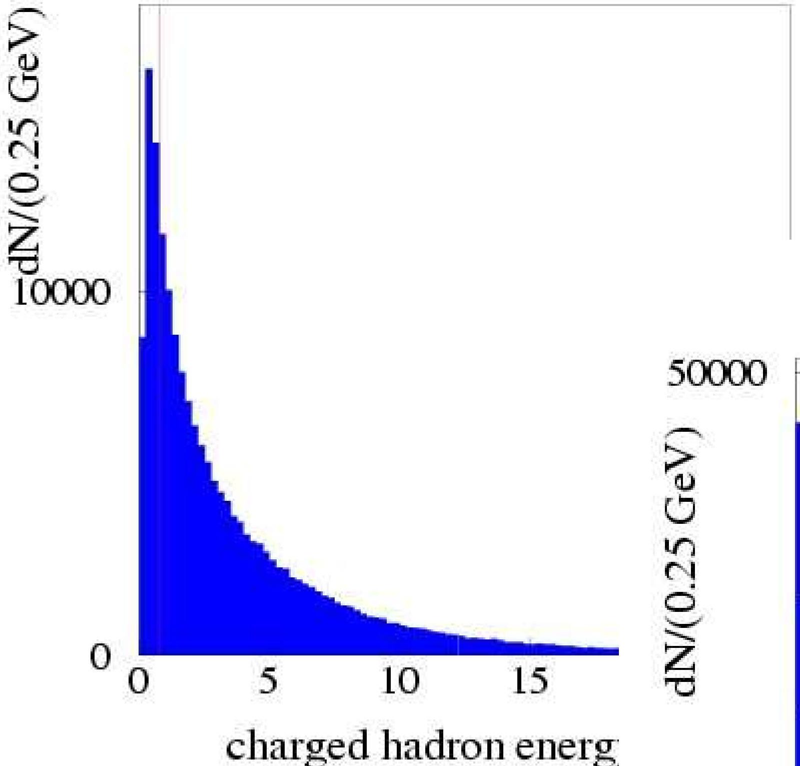
neutral hadrons: seen in Cal only

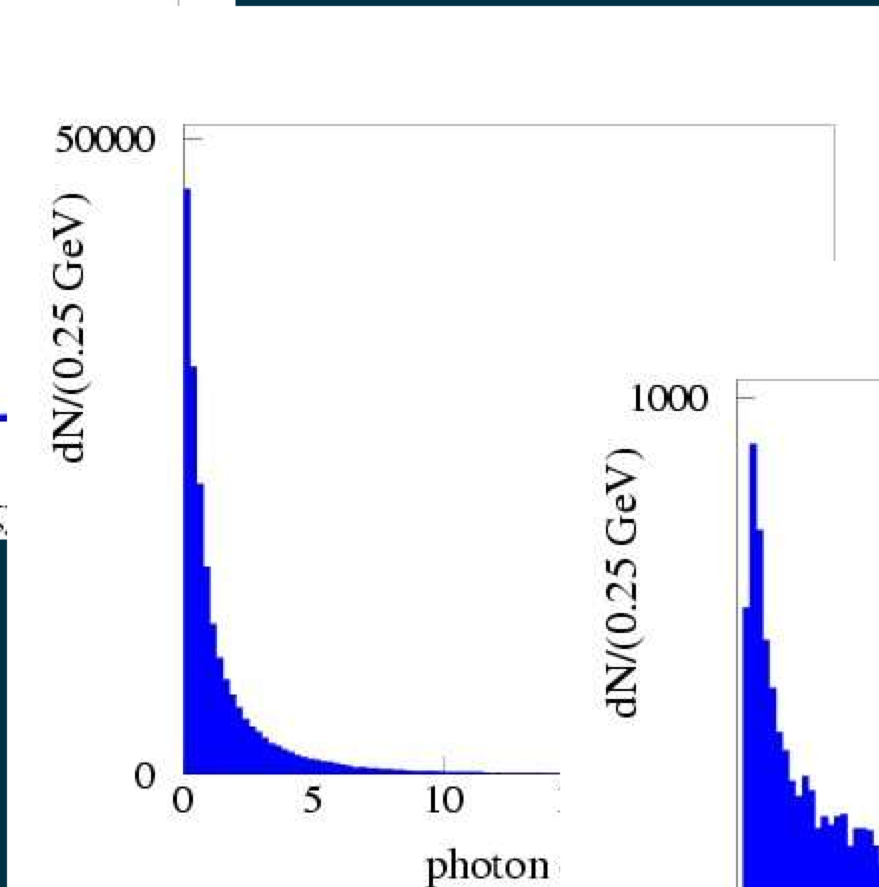
Fractions: charged tracks 60%
neutral hadrons 12%
photons 28%

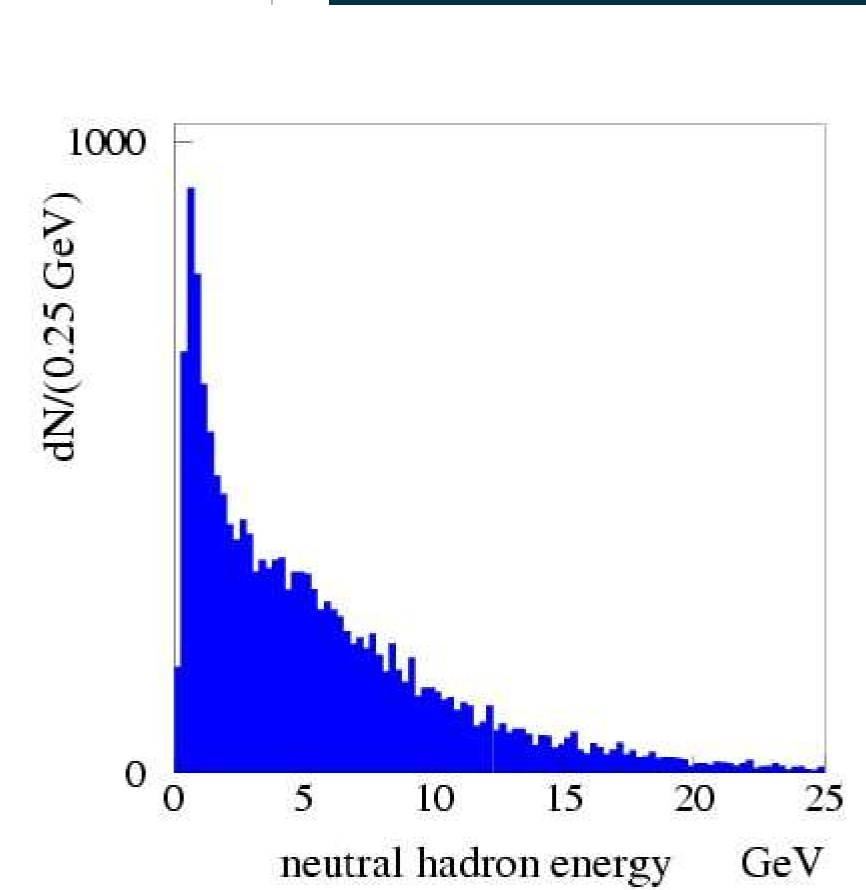
It depends on the type of events

Energy spectra

$E_{\gamma} = 1/2\ E_{ch}$







Most is rather low energy!

You need to measure very accurately the muons $\Rightarrow$ B + L^2

for a given precision A on dp_t/p_t we play on δs, B and L for $\frac{\delta s}{B L^2} = 0.04 A$

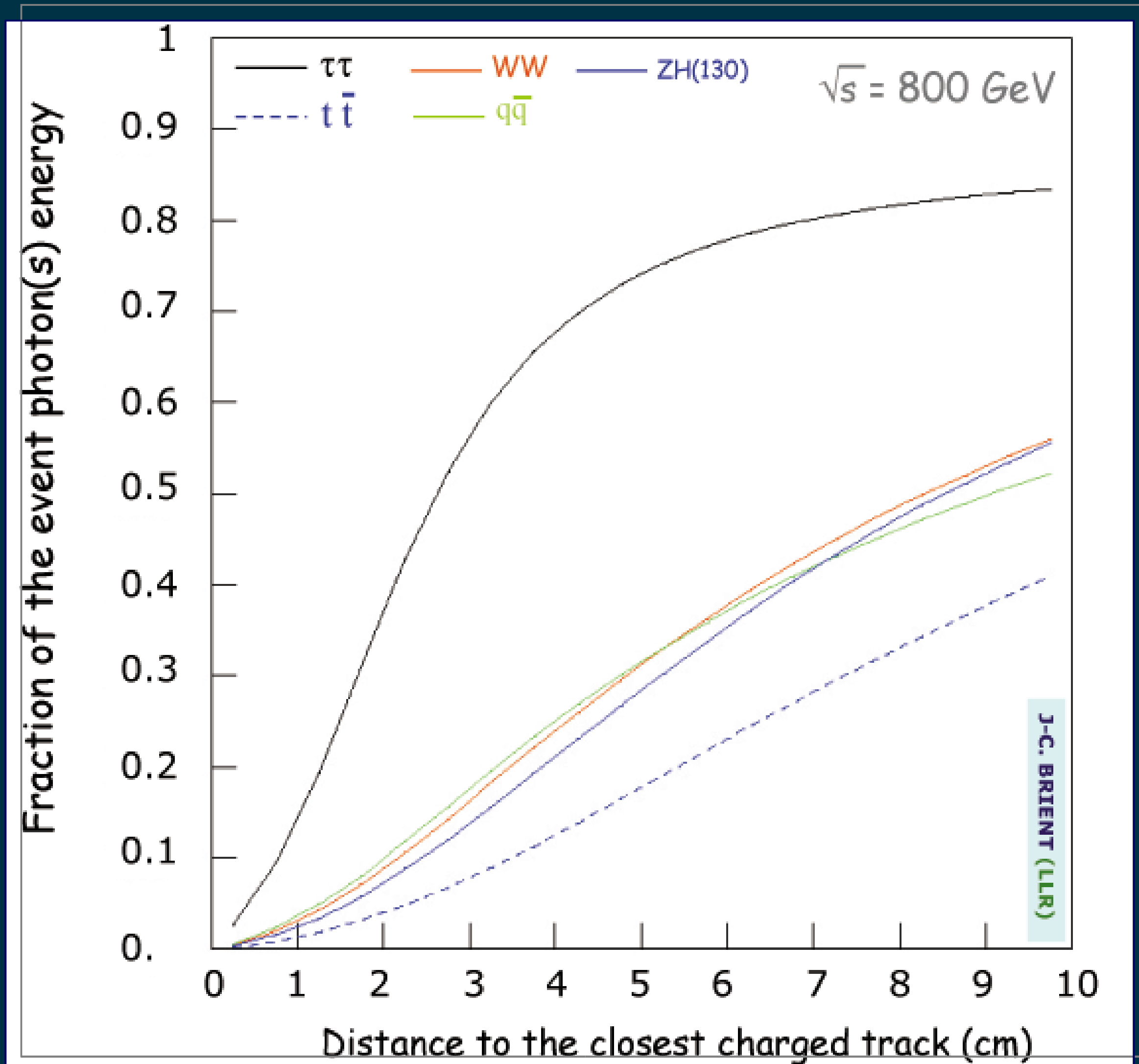
High B necessary to keep the background away from VDET
It is not really an alternative to L, a lot of physics at low angle
where to separate the particles we can count only on distance:
Z opening angle at 450 GeV: 200 mrad, 40cm at 2 m !!
charge track opening at 10 GeV for 4T: 24 cm at 2m !!

High B on rather low energy particles in jets,
smears the jet and distorts
completely a purely calorimetric approach
from the point of view of mass and angle

We need to get the charged particles from the tracker.

Looking at the photons

You need not to let them interfere with the hadrons



At the ECAL entrance

And for the neutral hadrons ...

Reminder on the analytical energy flow basics

What are the old ideas on how to handle the problem?

The isolated particles are not much of a problem
on top of the intrinsic resolution of the detector

τ ?

The jets are interesting for their flow of energy
if the dijet can be resolved and the mass measured
and the detectors have hadronic calorimeters not to let
the neutral hadrons escape (hermeticity).

How to handle hadronic calorimeters?

energy flow

from Jeju

There are two extreme and trivial solutions:

- use only calorimetry segmented according to the hadronic shower size or the jet size
- develop a detector such that you identify and measure separately every particle produced

The first one looks much easier and if the calorimeter is a good one, well compensated, it should do the job, you can preferably forget the magnetic field
if you do not care about charge and muons

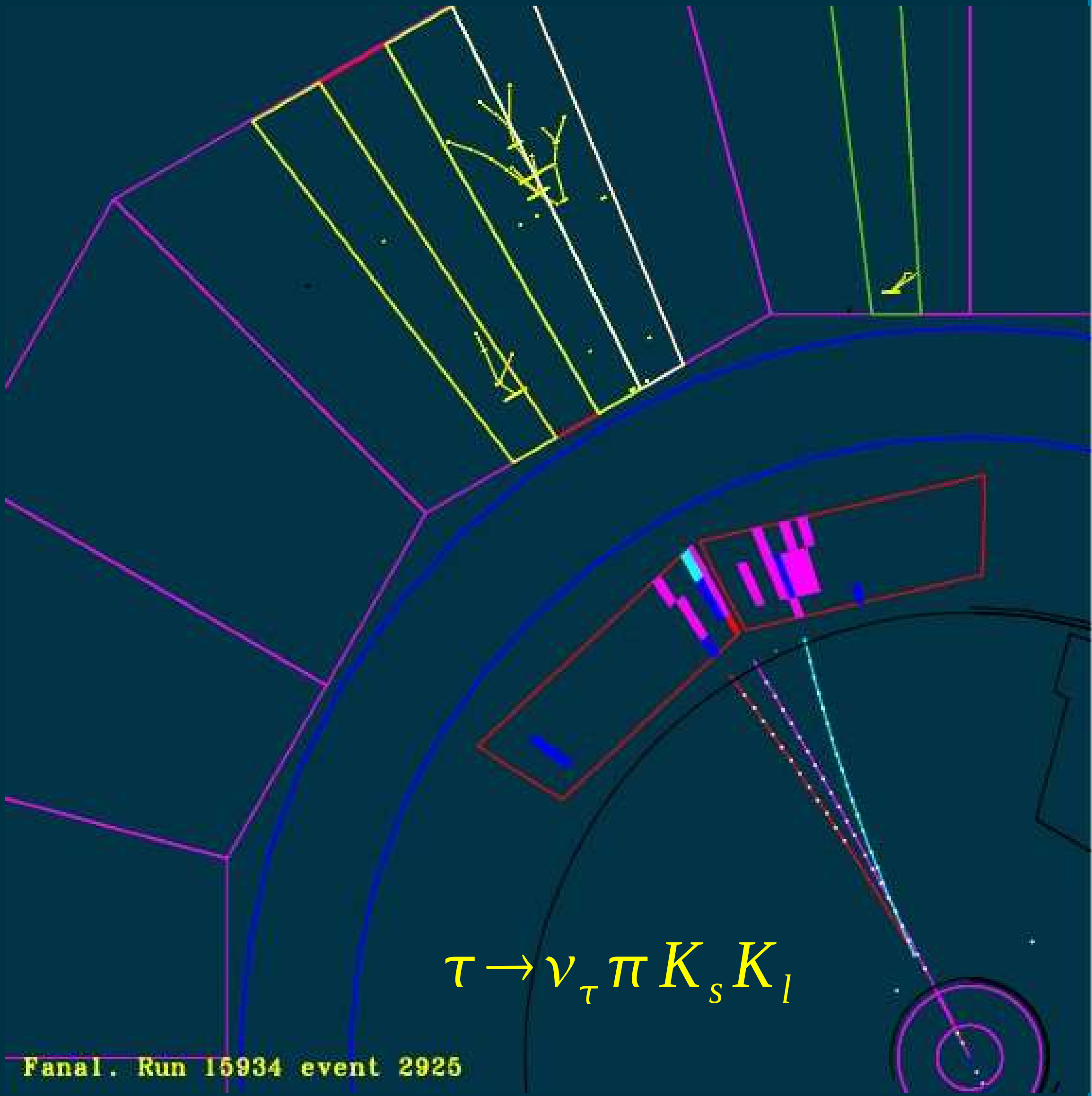
The second is an asymptotic solution, can you get close enough to the perfection that it is useful?
That is the analytical energy flow approach used at LEP and in particular in ALEPH.

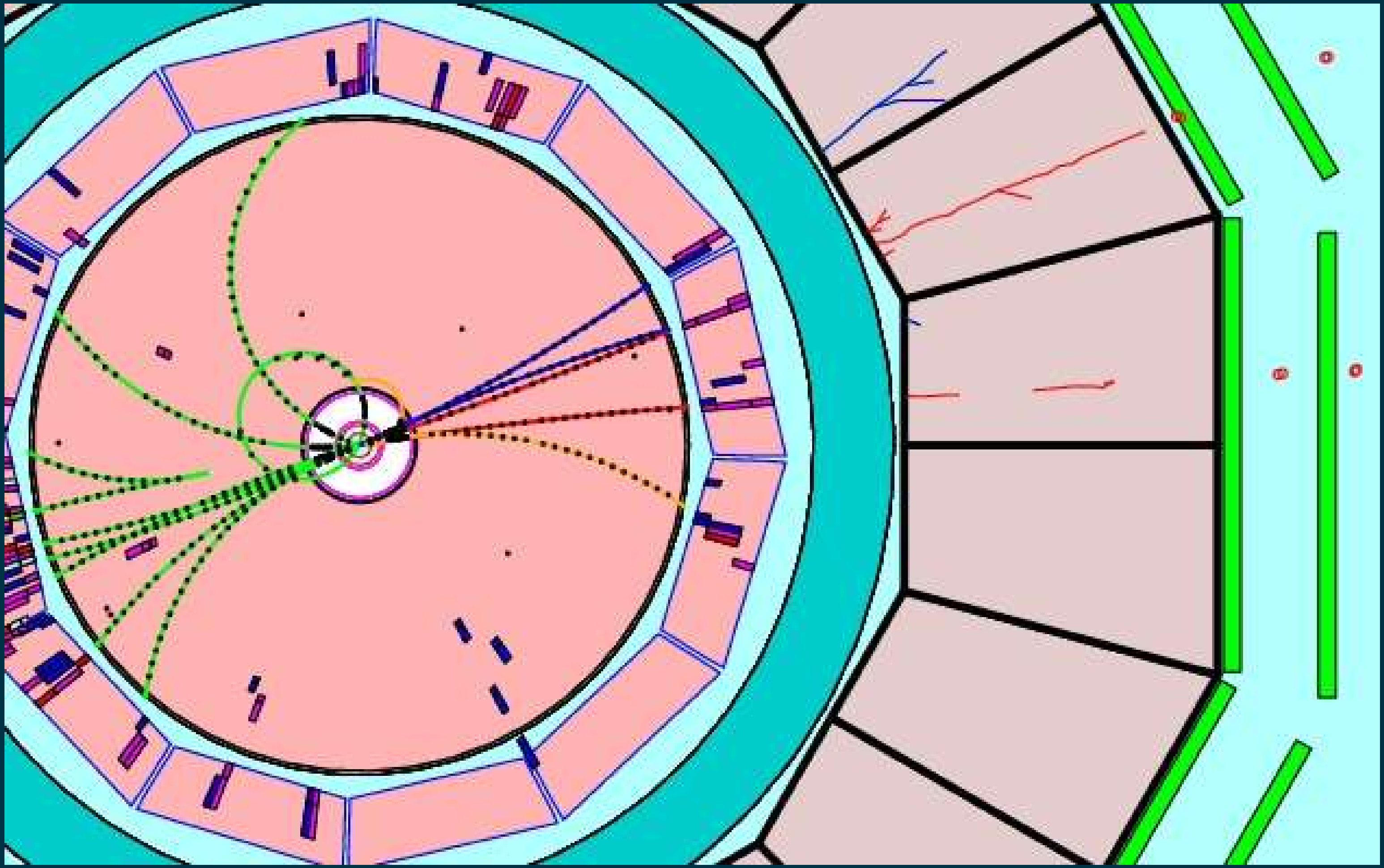
A historical example of energy flow method: ALEPH

as described in "Performances of the ALEPH detector at LEP" NIM A 360 (1995)

To understand the value and the weakness of the method have first a look at the detector it is built for:

TPC
ECAL 3 layers 3cm cells
Coil
HCAL towers 4x4 ECAL
+ digital pattern





$$B_s \to \psi ' \phi$$

The method rests on - topologic separation
- identification
and - subtraction after appropriate weighting

Step 1 - Cleaning
Step 2 - Build calorimeter objects from connected tracks and Cal clusters
For each such object
Step 2 - Charged tracks from IP or V0 = charged energy (π)
Step 3 - For electrons Ided remove cal energy up to P+3σ
Step 4 - For muons Ided remove cal energy up to ...
Step 5 - γ's and π^{0}'s Ided = neutral elmgn energy
Step 6 - neutral hadronic energy =
remaining cal energy (weighted) - (track energy + error)

This last operation bears the weakness.
The neutral hadronic error contains fluctuations from charged showers
It was forced on us by the presence of the coil
and a still inadequate grain

Result:
A purely calorimetric energy resolution of $\frac{1.2}{\sqrt{E}}$
without tricks

goes to $\frac{0.6}{\sqrt{E}}$

when a perfect Id would provide $\frac{0.3}{\sqrt{E}}$

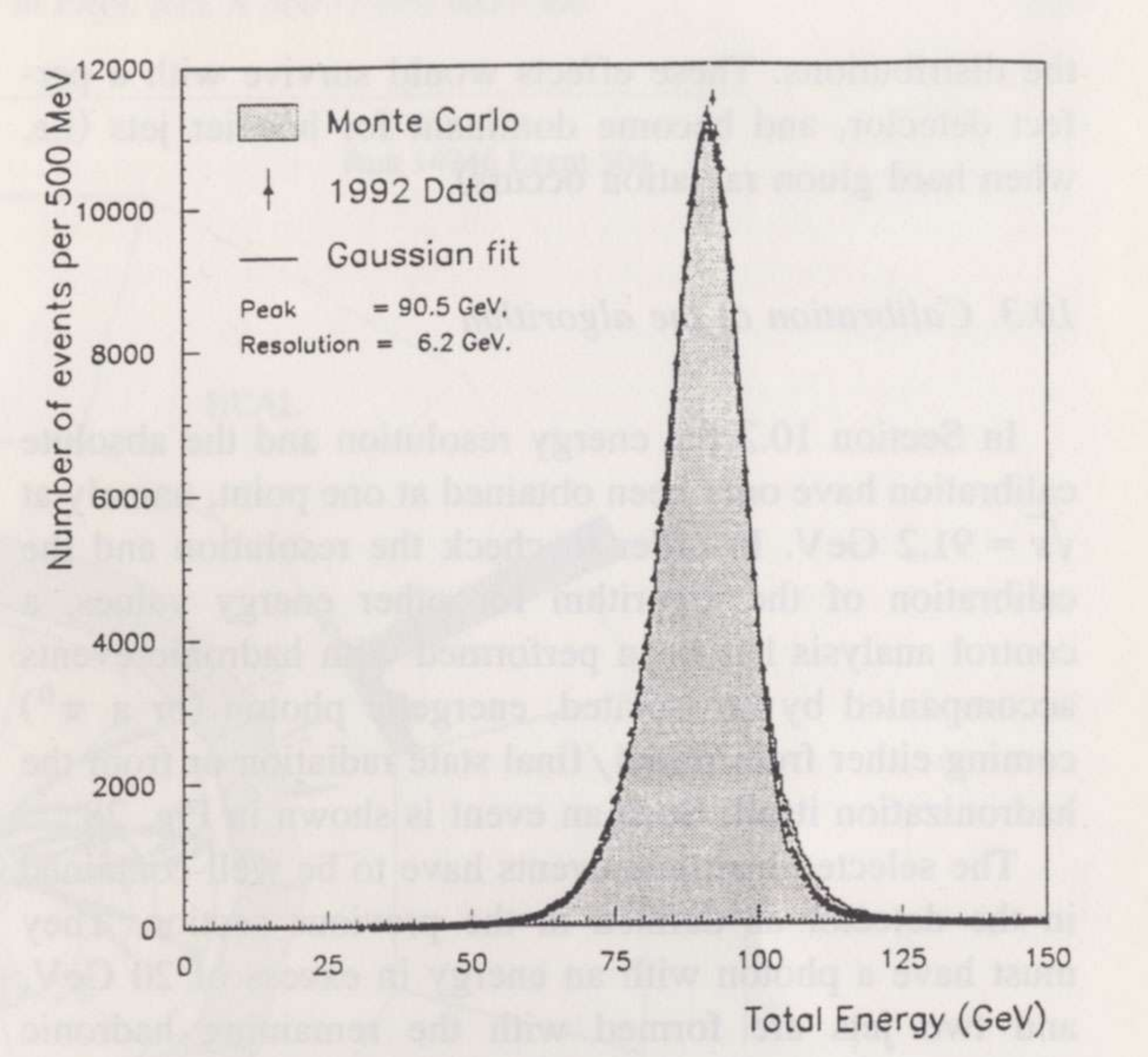


Fig. 26. Distribution of the total energy for well-contained hadronic

angular jet resolution
18 - 19 mrad
1/2 from low energy tracks and ν's, 1/2 from detector imperfections

An example of optimisation of the resolution: H1

The problem of hadronic shower is known to be related to the different response of the calorimeter to the hadronic component and to the electromagnetic one, i.e. π^0

There are two solutions: one is to adjust the response to be equal, the other to identify the two components and weight them adequately

This last solution can be obtained by hardware or by some recognition, this is the case in H1 with a liquid argon calorimeter...

and that is what we recommend

These methods to optimise the hadronic resolution are often referred to as "energy flow" techniques as well and indeed the ideas behind are similar

Measurement of Hadronic Energy

electromagnetic component:

e. g. π^0, η, γ

- pair production, bremsstrahlung, ionisation

$\Downarrow$

high energy density

- fluctuating electromagnetic component: energy dependent

$\Leftarrow$

hadronic component:

e. g. $\pi^\pm, p, n, \ldots$

- nuclear reactions: energy losses due to short range fragments, broken up nuclear bonds

$\Downarrow$

low energy density

- e. g. relative fraction of π^0 production in nuclear interactions increases with energy

- response: $\frac{e}{\pi} = 1.35$ (@10 GeV) energy dependent

Towards a New Weighting Scheme

new weighting procedure: using tabulated correction factors ω on cell level

reconstructed energy in cell i ⟵ $$E^i_{\rm rec} = \omega\,(E^i_0/Vol^i, E_{\rm group})\cdot E^i_0$$ ⟵ energy in cell i (signal)

energy density: "distinguish" between em and hadronic deposition

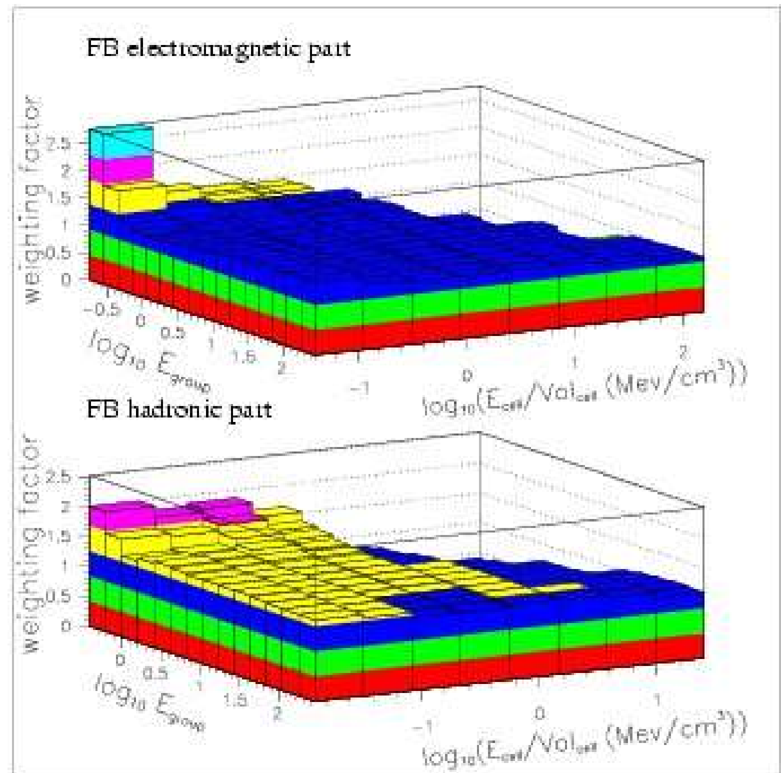
energy of group of clusters: energy dependence of $\frac{e}{\pi}$ and fluctuations

- reconstruct hadronic shower differentially
- derive weighting factor tables wheelwise (EMC, HAC) using single π detailed simulation
- energy range: down to noise level energies
- additive noise correction
- calibrate with real DIS data: adjust wheelwise $p_{\rm t}^{\rm had}/p_{\rm t}^{\rm e} \to 1$

⇒ increasing weighting factors ω for:

– ↓ $E_{\rm group}$ (↓ π^0 fraction)

– ↓ energy density (hadron–like clusters)



Christian.Schwanenberger@desy.de

CALOR 2002

As a result of these corrections depending on
the energy density and the overall energy of the cluster

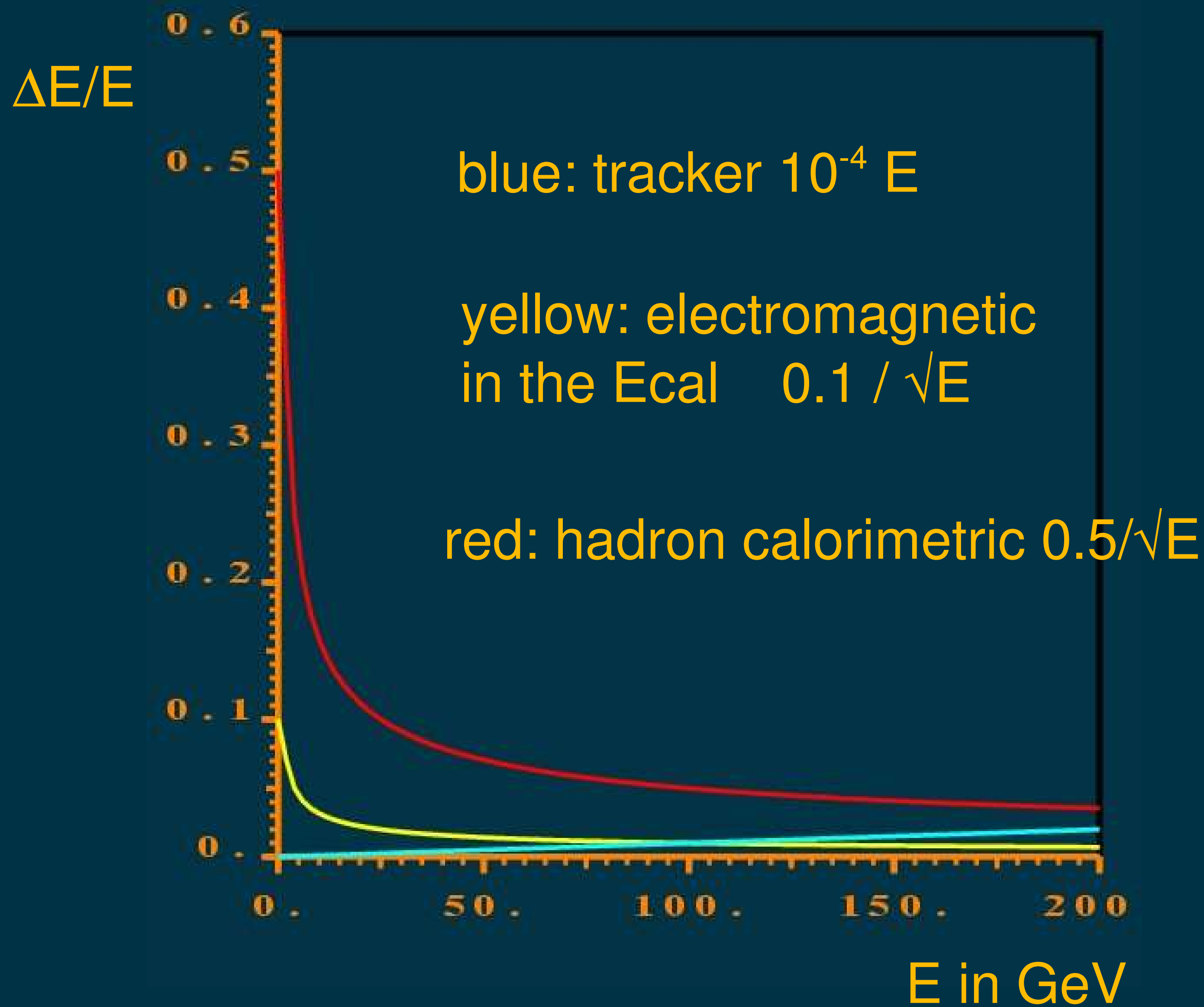
less tails,
more Gaussian distribution
better resolution (by 15%)

An approach by neural net on LC simulation gives an improvement of 30%.

This means that we have to have the capability to distinguish electromagnetic and hadronic components.
This may rely on energy density measurement if the cell size is adequate

Remember that it is possible to tune the response by playing with the interaction/radiation length ratio, (10 for Fe, 30 for W).

Resolution figures



In the domain of interest the tracker is always better.

Only at very high energies does the Ecal compete for electrons

The idea is then:
for a detector ideal in separating the different particles
- the charged tracks will be measured from the tracker
- the photons from the Ecal
- and only the neutral hadrons will be measured by both calorimeters

The challenge is 1) to effectively separate
and not create fakes
identify the decays
2) to optimise the resolutions
and particularly hadronic

Once the decays (secondary vertices) have been properly found we can write the 4-momentum of a set of particles as

$$P = \sum P_{charged\ \ particles} + P_{\gamma} + P_{neutral\ \ hadrons}$$

and

$$\sigma^2 = \sigma^2_{chp} + \sigma^2_{\gamma} + \sigma^2_{nh}$$

In this ideal case with the values quoted above

$$\frac{\Delta E}{E} \approx \frac{0.18}{\sqrt{E}}$$

The photon resolution plays little role and the effort has to be on the hadronic resolution: going to 0.3 would achieve 0.12 on the jet

But for a real detector two effects play a role

The existence of an effective threshold on
-charged particles due to the high magnetic field needed for background, precision and separation
-photons due to cell threshold and physical background

The probability of confusion
-efficiency of track reconstruction
-vertex misidentification
-wrong associations between tracks and calorimeter cells

$$\sigma^2 = \sigma^2_{chp} + \sigma^2_{\gamma} + \sigma^2_{nh} + \sigma^2_{conf} + \sigma^2_{thresh}$$

The main enemy is confusion, far more than resolution and the design of the detector has to address this point first

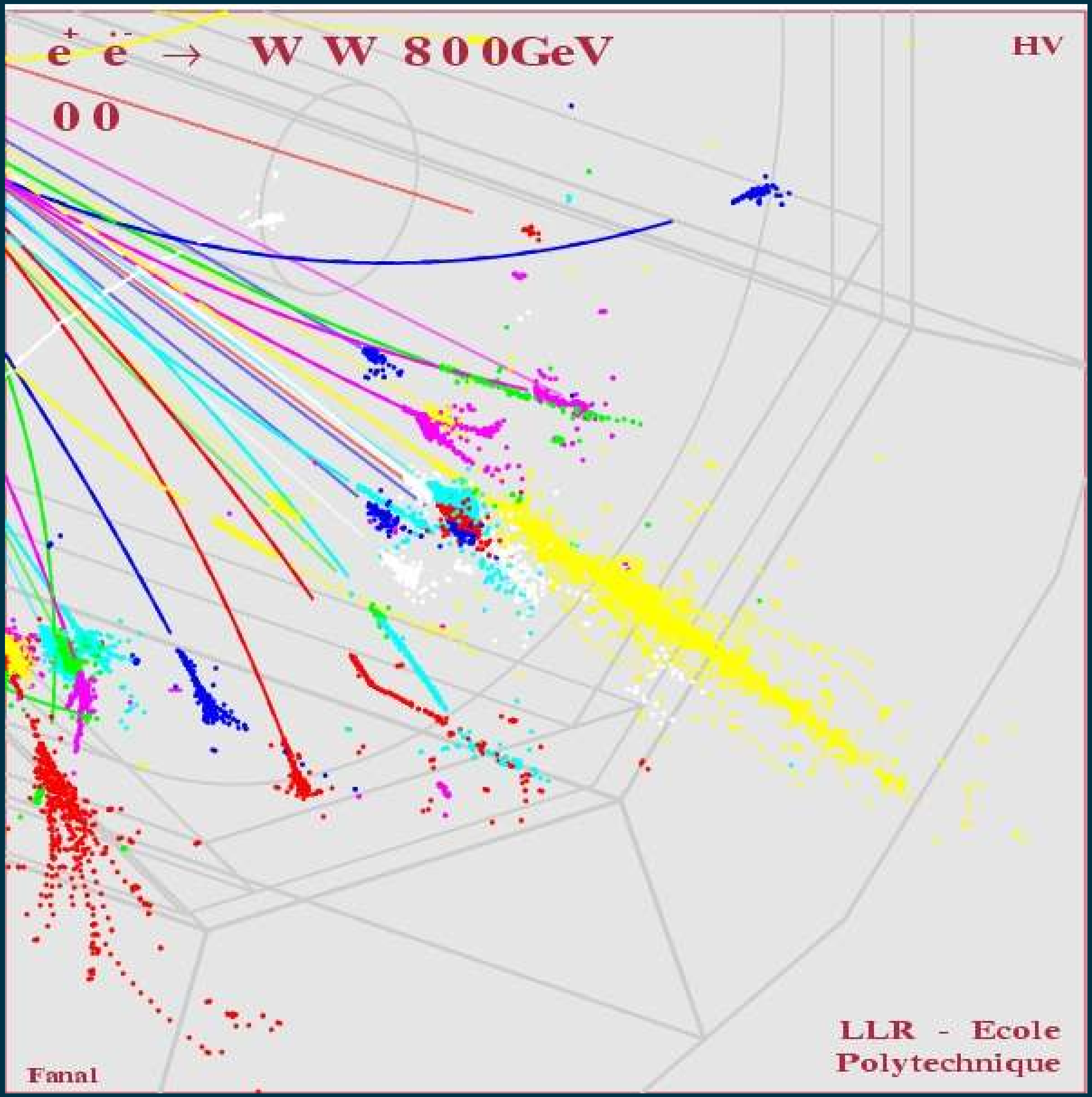
Recipe for a calorimeter:

as far as you can afford

electromagnetic part: large ratio l/X0
very dense
very granular

no gap to the

hadronic part: dense, providing narrow showers
with an adequate l/X0 ratio
very granular



These showers, aren' they as conspicuous as the nose in the middle of the face

like

But most often we prefer to apply a 90 ° rotation

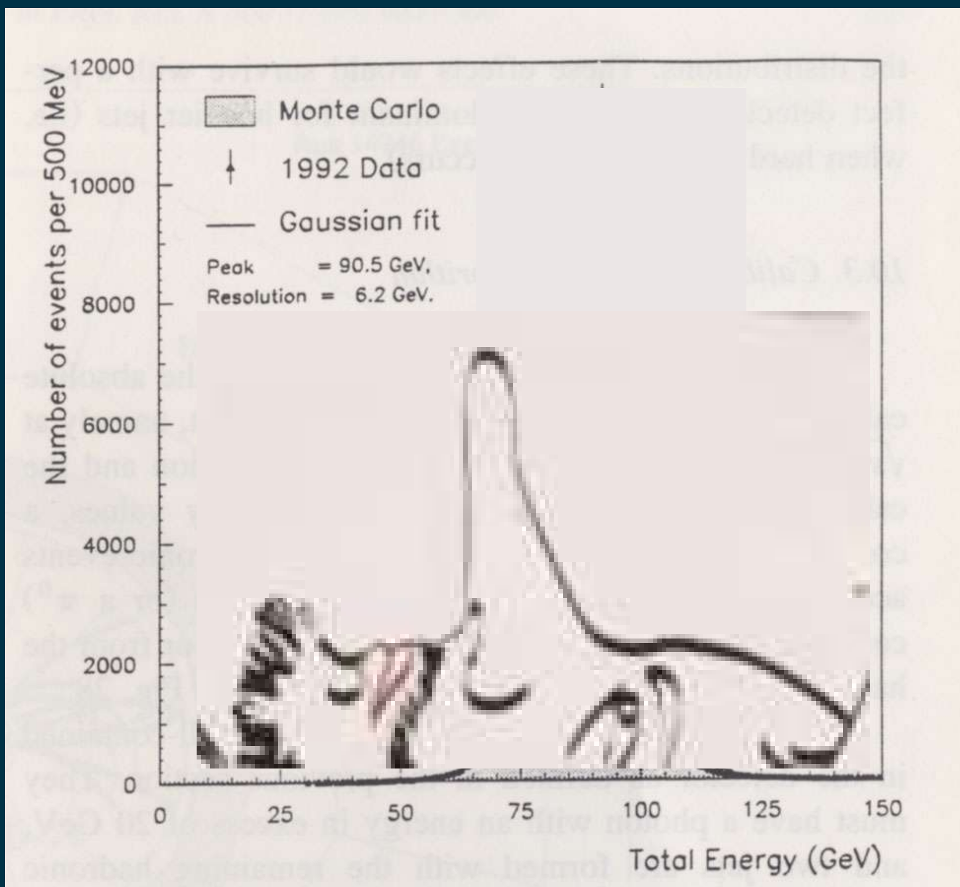
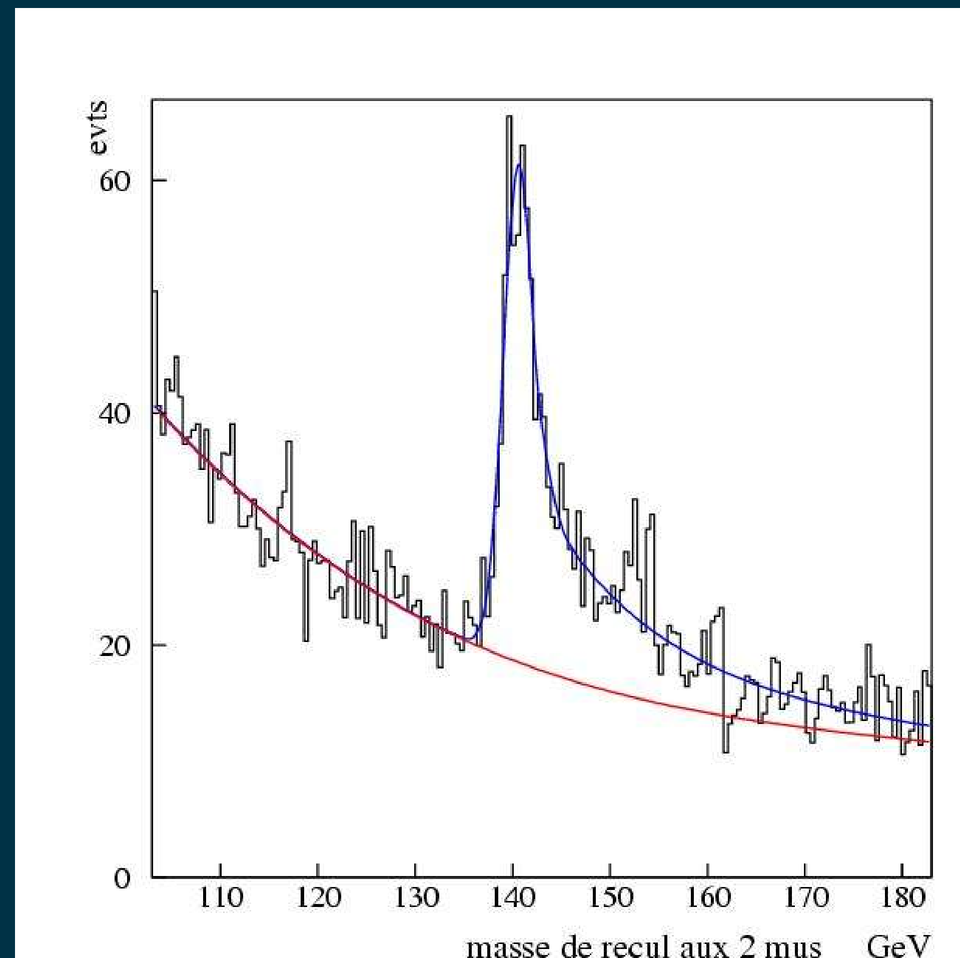


Fig. 26. Distribution of the total energy for well-contained hadronic



Back to being serious

possible algorithm for such a flow analysis

goes by descending order of clarity

tracks with vertices, V^0's and γ's

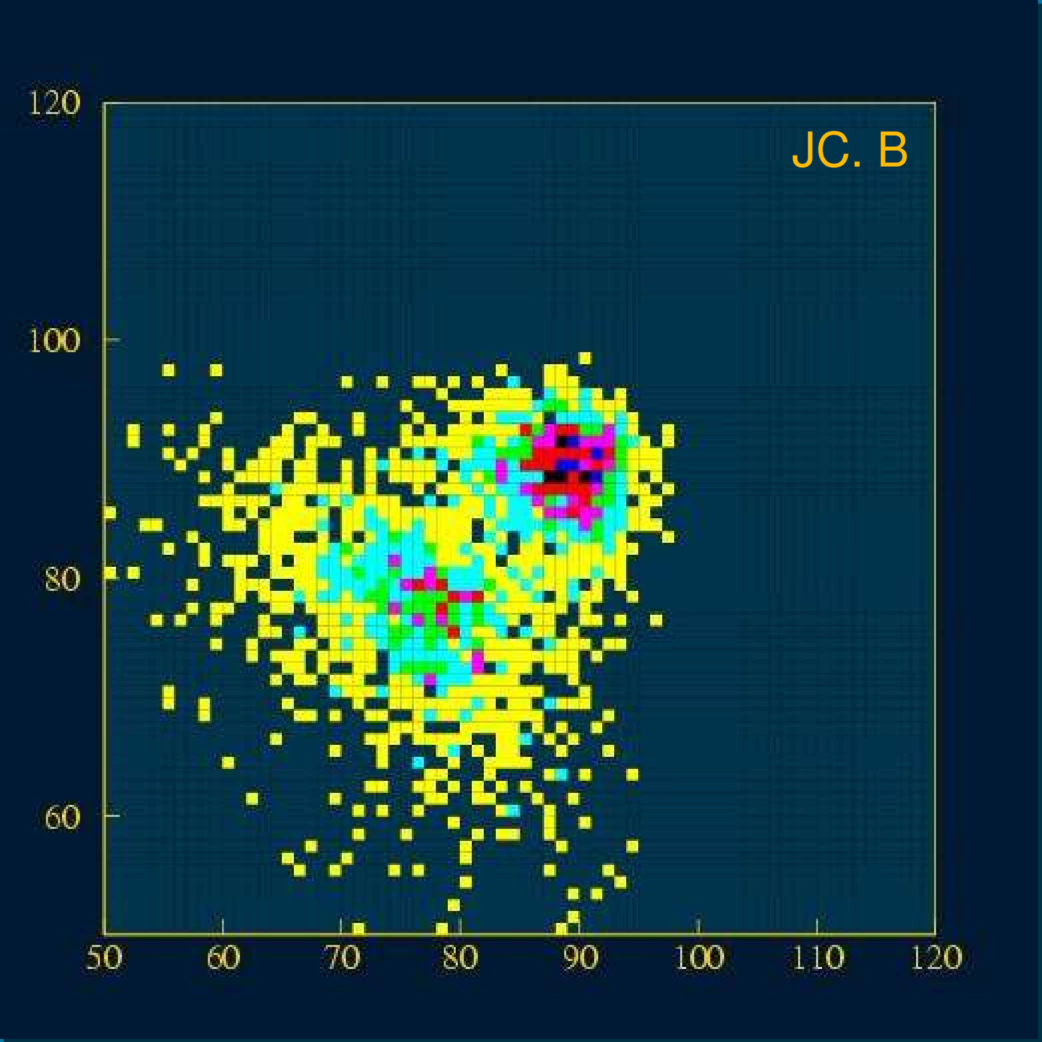
electron identification

photons from the Ecal knowing the tracks

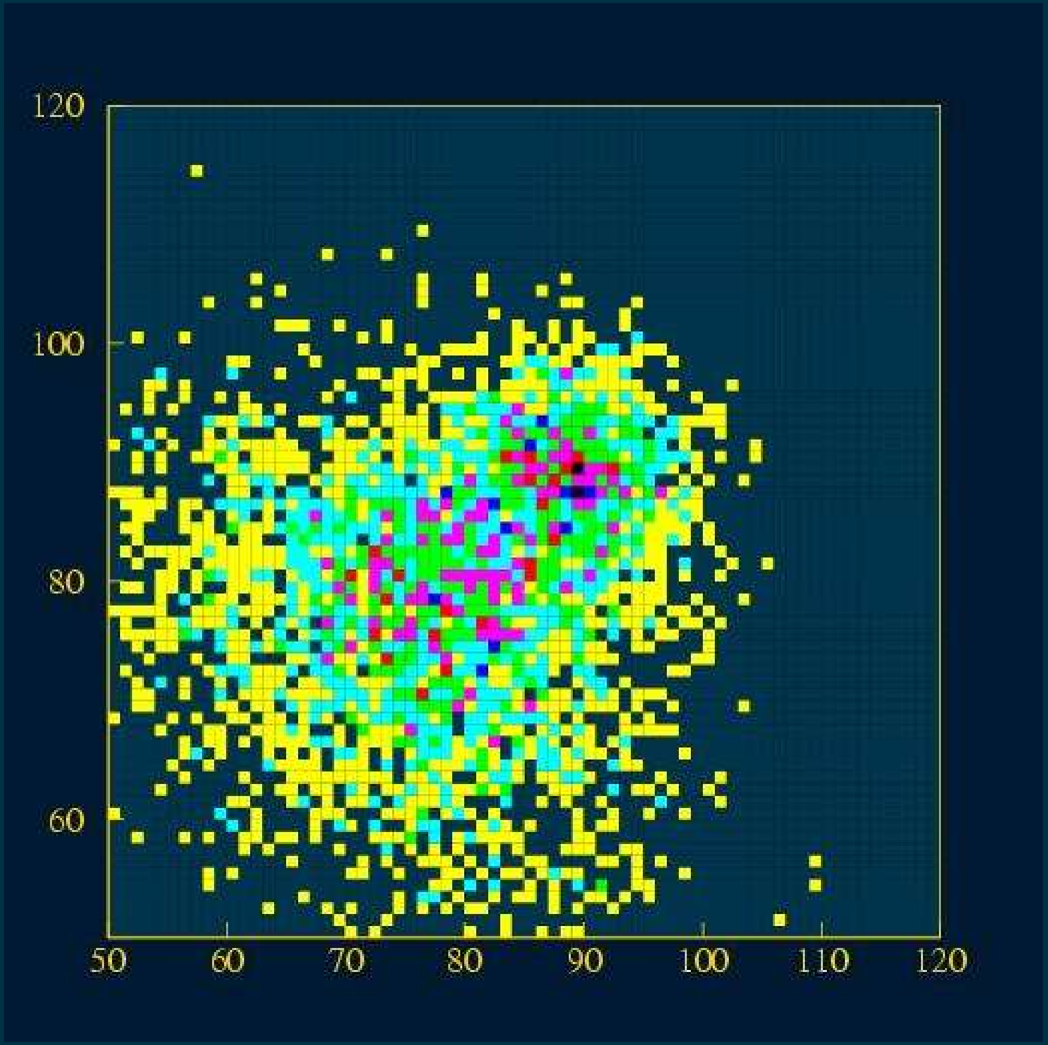
muon identification

neutral hadrons, by topology with energy balance check

then build masses, energies, momenta for any set



Do I need to present these plots?



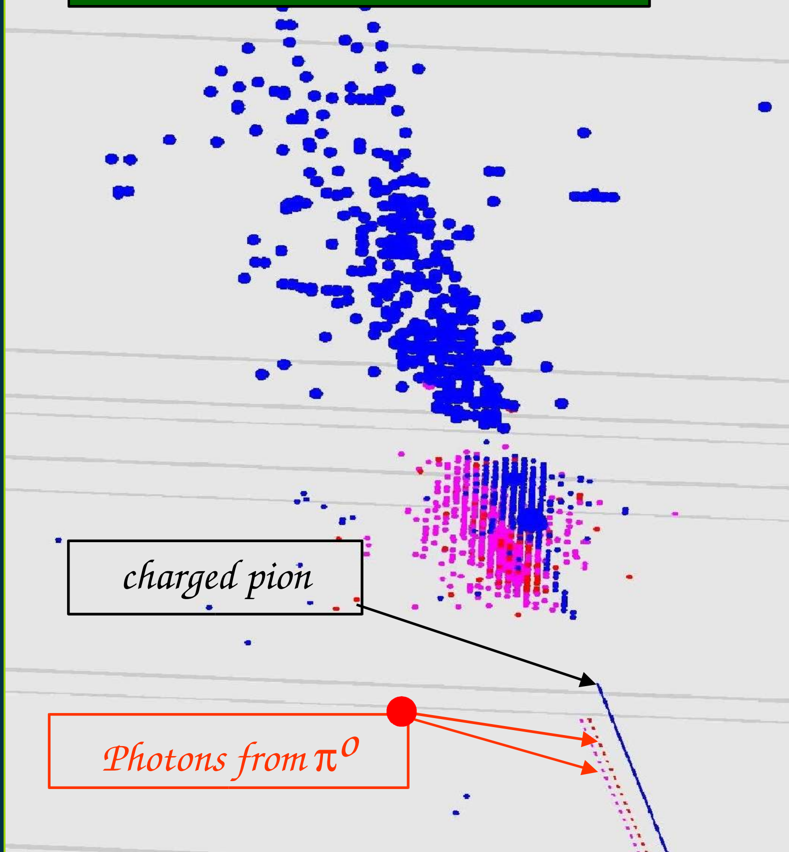
And with a good particle flow,
not only can you manage the jets
but you can also manage the taus

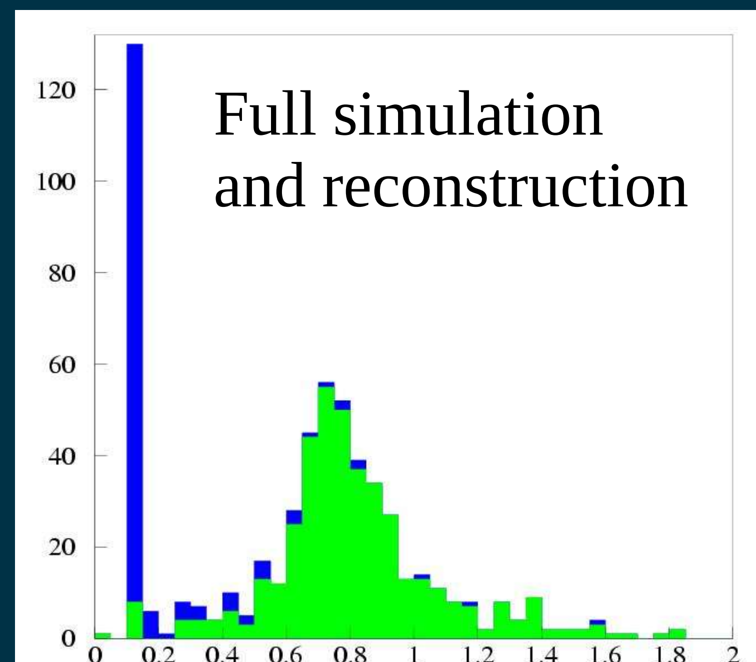
Tau decays ID is essential for

ID and polarisation measurement

	Jet mass < 0.2	Jet mass in 0.2-2
→	82%	17%
→	2%	90%

(250 GeV) →



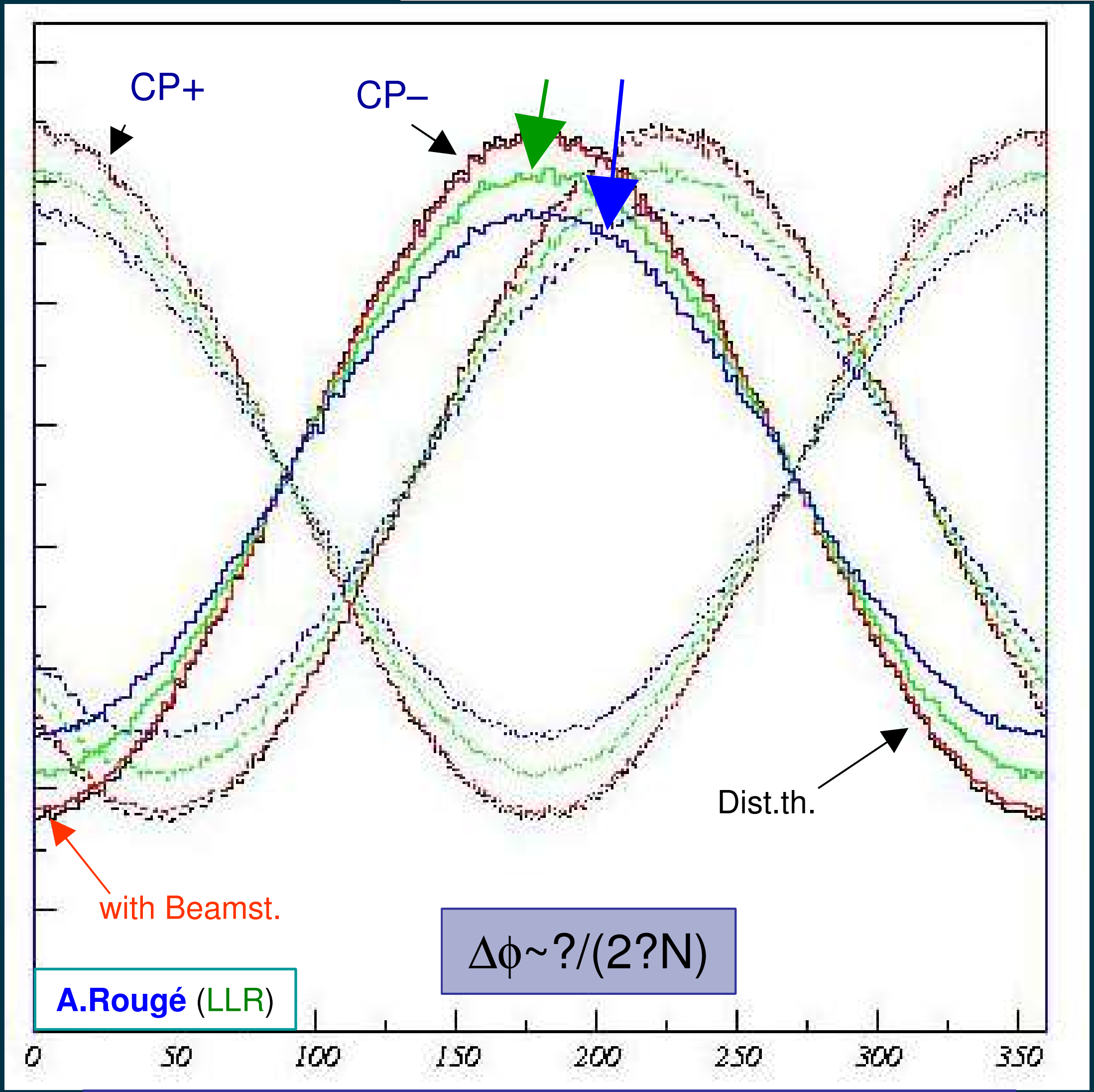


JC.Brient
Calor 2004

CP violation in the Higgs sector

e^+e^- ZH at ?s = 230 GeV

Z μμ, qq and H + – π ν ρ ν



CP angle analyser

φ angle is reconstructed from Z energy/direction <u>and</u>

1 - decays channel selection
2 – reconstruction of

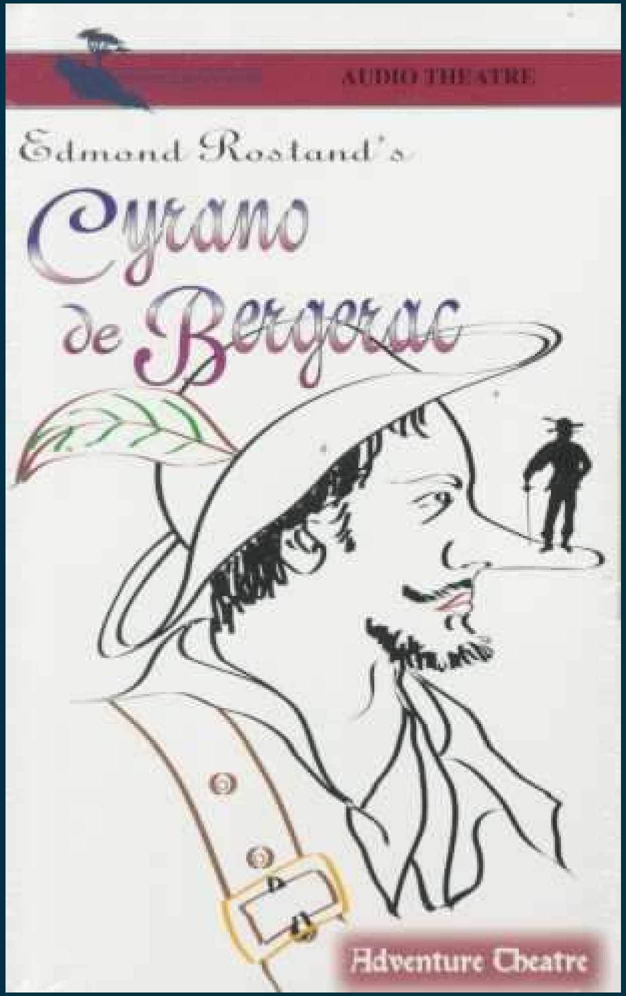
π and ρ energy /direction

JC.Brient
Calor 2004

Conclusion

An efficient detector
is highly granular
has a smart software to separate topologically, by shape and energy,
and optimise the hadronic resolution;
clearly it is also capable of excellent lepton identification
and measurement of a

Flow of particles



What
about
a good dinner?