After four long days listening on calorimetry

or more exactly

on calorimetric devices and technologies

The conference started « in medias res » rather by an « état des lieux »
but for the lessons from the Tevatron.

a certain lack of critical review

not a summary talk

rather a set of inconclusive remarks

for the inocuous title
of « closing talk »

A perspective through calorimetry

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Calorimetry for the High Energy Frontier

I would like first to thank the programme committee

of Top CHEF 2013

to have given me the opportunity of cooking you this presentation

We have seen in this conference

the experience of Tevatron calorimeters
the past and future flowering of LHC's calorimeters
the atmospheric or spatial calorimeters for astrophysics,
the new trends for LC detectors and others

presenting an impressive change of scale.

But what is the energy frontier ?

slowly moving with the accelerator developments

consider a range from 1 GeV to few hundreds looking from a distance

We saw various designs

THEN

What drives the choice of a design?

the physics under study with its different faces
the accelerator specificities,
the available technologies?

But why to optimise the same physics are the solutions that different ?

Is this the consequence of
local minima in the optimisation,
a bet,
a personnal taste,
a political behaviour, you need to look different
cost ?

looking for history

Few historical examples

Tevatron :	CDF	sampling with scintillator	
	D0	sampling with U and LAr	
LEP+SLC	SLD	sampling LAr	
	Aleph	sampling Pb & gas	Fe & gas
	Delphi	sampling Pb & gas	Fe & gas
	OPAL	homogeneous Lead glas	
	L3	homogeneous BGO	
LHC	Atlas	sampling Lar	Fe & scintillator
	CMS	homogeneous PbWO4	Fe & scintillator

We distinguish immediately two schools : homogeneous for energy resolution
sampling for spatial resolution
(electromagnetic calorimeter)

What is à la mode today ? compensation, stability, fun ?

What will be à la mode tomorrow ?

U, PFA ...

The way techniques evolve

The ebb and the flow of calorimetry techniques

A little digression on digital calorimetry
and the sinuous way things go

In 1978 I joined PEP4 (TPC) at LBNL in the group of Dave Nygren
but worked mostly on the electromagnetic calorimeter headed by Bill Wenzel
it was a giant SiPM with no Si, wire chambers working in Geiger mode stopped by nylon threads
this was a digital electromagnetic calorimeter
but the nylon dissolved and the chambers were switched to streamer mode.

In 1981 we tested something similar with 5mm cells for LEP
but the saturation for LEP energies was too strong, we switched to avalanche mode
in the Aleph electromagnetic calorimeter.

The Aleph hadron calorimeter used Iarocci tubes parallel to the axis
I used this 2d digital pattern for particle identification with Harbor and for
energy measurement using weights of second order in the clusters size
That worked well.

Other experiments did it

We proposed a digital gaseous calorimeter for Tesla, presented briefly at LCWS 2000 in Fermilab
I discussed then with S Magill who convinced himself that it would be great to
prototype this at Argonne.

etc.

The impact of technology

What strucks me most is the leap in technology

The evolution of calorimetry is driven
by the problems raised by new physics fields, new energy domains,
new rates

but is enabled by the evolution of technology

The impact of the technological (electronics) evolution :

the high level of integration mixing analogue and digital signals
permits to increase the number of channels by 1000
if the heat can be managed
if the sensitive medium or better just the read out
can be partitioned in small cells
the absence of a global trigger

The impact of new technologies : SiPM

The impact of analysis (reconstruction) methods and computing Grid toward a goal ?

What do we want to achieve with a high energy (frontier) detector ?

That may not be too difficult in an astroparticle detector,
identifying and measuring the particles in the cosmic flow,
records a one particle event

It is not so easy to define for a collider and that may be the reason
we have been unable to coin a better defined word than « detector »
something like a “stuffmeter” or a more pedantic “pragmameter”.

We would like to trace what happens at the time of the collision and
for a little while, having access only at the traces of the final products.

Then the detector has to provide all possible information on the final products
or groupings of final products,
charge
energy and momentum, identification
originating vertex
spin state.

not ot speak about pile-up.

If you want to measure the charge, there is no way except using
a field, magnetic or electrostatic, the second being more cumbersome

and to obtain an isotropic capability without material close to the interaction,
and without perturbation of the incoming beams is like squaring the circle.
Atlas could be a good example.

The other point is the behaviour of the measurement error with momentum

$$\frac{\delta p}{p} = \alpha p$$

with a typical α from 10^{-4} to 10^{-3}

$$\frac{\delta p}{p^2} = \frac{8}{0.3 B L^2} \delta s$$

2.6

Going to higher energies with an acceptable relative error means
higher field and larger detectors, a cost to estimate, an interference with BDS..

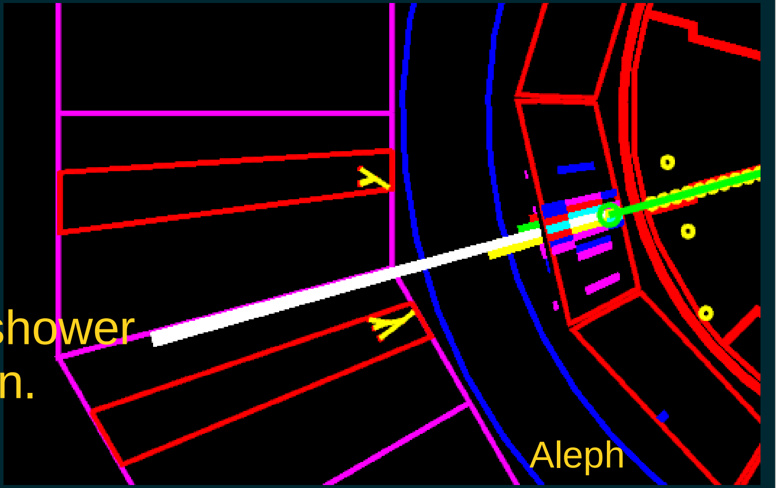
Forgetting about the charge, like UA2 or D0 did dare to for a time,
you can consider shooting your particle(s) straight into
a block of material meant to absorb everything
and you measure what happens to your block, its change in temperature

That's calorimetry

To be absorbed, the particle has to interact with the material
and develop a « shower » of interaction products themselves interacting

a self-similar pattern.

If the incident particle is an electron or a gamma, the mass of the electron being much smaller than that of a muon or a pion, almost all the particles in the shower will be electrons and photons.



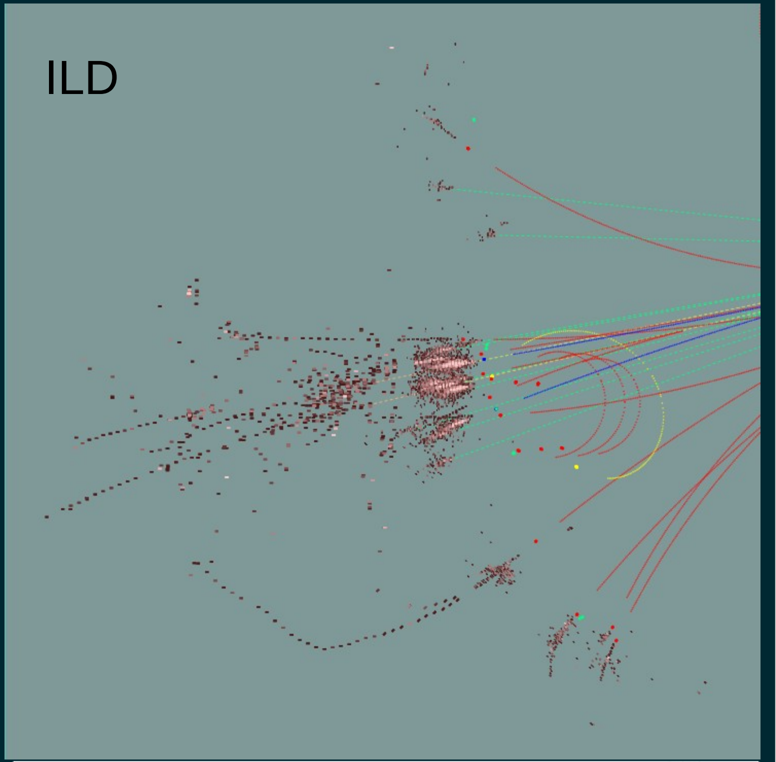
That makes an electromagnetic shower very specific,
characterised by radiation length and Molière radius.

but do not forget that at a tiny level your shower will produce
muons or pions which could hamper your identification of a shower
you could also by chance observe a deep inelastic interaction.

If the incident particle is a muon, except at extremely high energies,
the energy will be dissipated only by dE/dx and the muon will penetrate
deeply into the absorber.

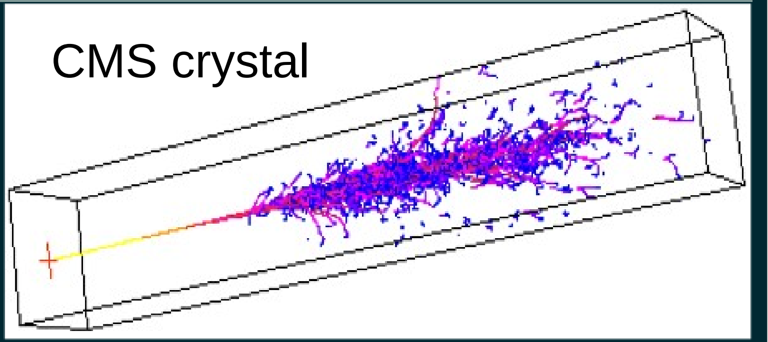
At energies under considerations muons can not be measured that way
but only by using a field, possibly after the calorimeter!

For neutrinos, they essentially go through if not at least of a few TeV energy
but at some point they will be detected in a calorimeter via the W
and are associated commonly to a charged lepton.



We are then left with strongly interacting particles,
hadrons which can be charged or neutral.
They will interact first hadronically
but the energy will be lost for a good part
in electromagnetic showers due to the production of π^0,
the rest by dE/dx in the charged branches
and through nuclei breakdown

the well known question of e/h and compensation.



Hadronic showers appear much less homogeneous
and dense than electromagnetic ones.

The shape of an electromagnetic shower being much better defined than a hadronic one

Separate as much as possible the electromagnetic and the hadronic part
by having a first part with a large ratio of interaction over radiation length.

When analysing the content of the calorimeter look first for electromagnetic showers
if not for tracks

energy, lateral and longitudinal shapes
identification of π^0s

The hadronic showers are sparse,

then overlaping showers can be reconstructed
with an adequate granularity.

momentum versus energy

All these absorption processes are essentially of stochastic behaviour
and then the resolution on the energy observed in the block has a behaviour à la

$$\frac{\delta E}{E} = \frac{\alpha}{\sqrt{E}} \oplus \beta$$

α depends essentially on the fraction of the energy absorbed which is observed
and may range from 1% to 25% in electromagnetic showers and 20 to 100% in hadronic

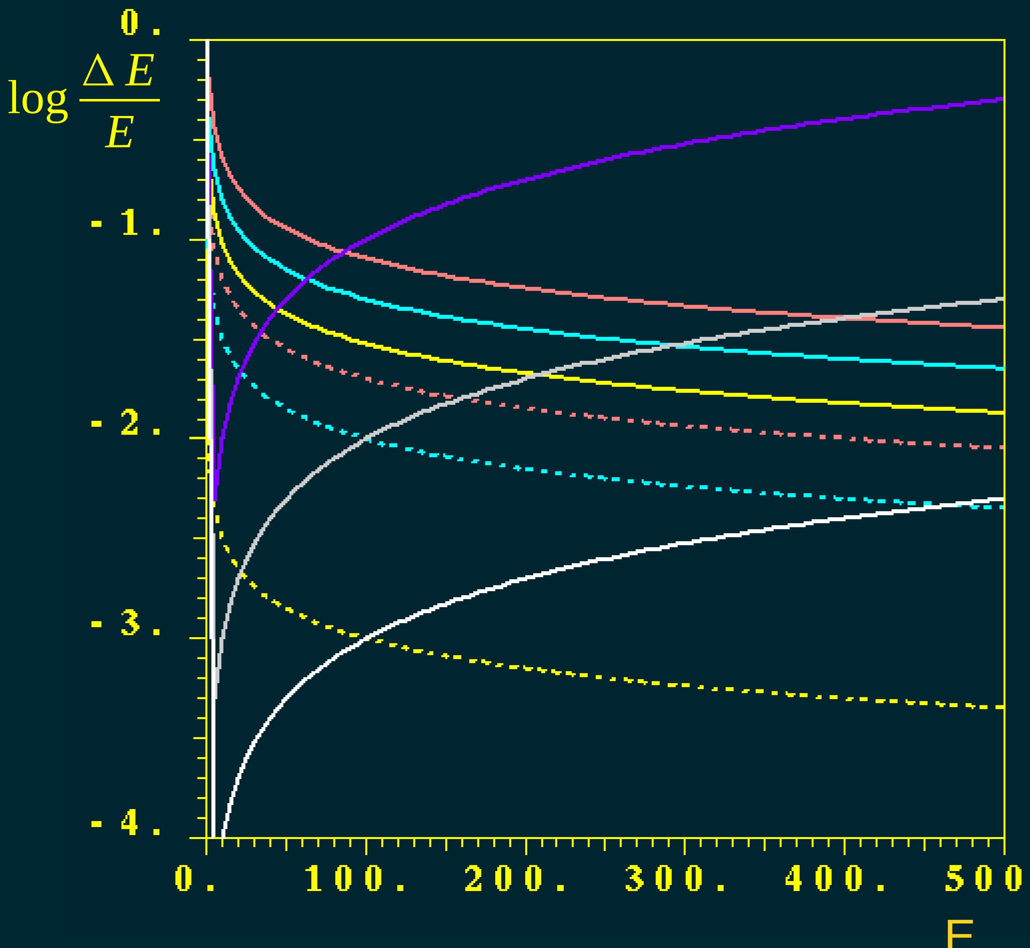
For illustration we take β=0.5% for electromagnetic and 3% for hadronic

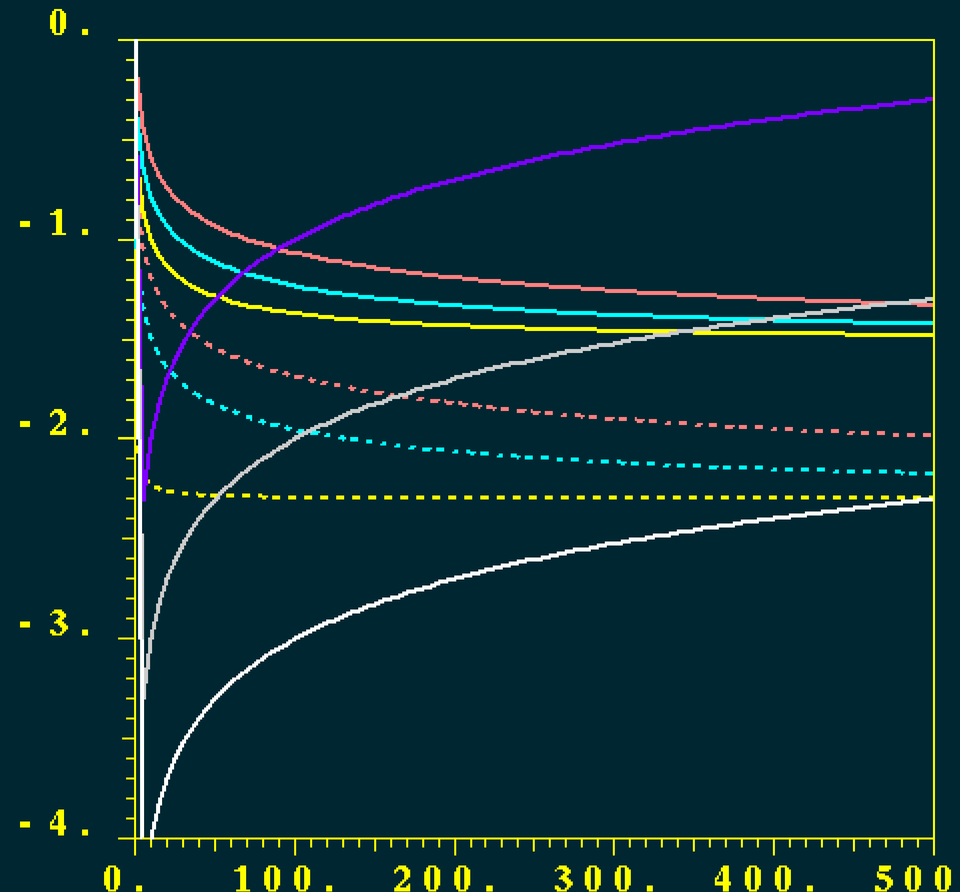
We can then compare for the charged particles
the measurement through a magnetic
field with a calorimetric measurement.

LHC and LC are well in the range
of ambiguity for hadrons.
But for charged particles,
if we are better than 10^{-4}
calorimetry does not bring much,
notice that the two measurements
are independent and could be added.

Remark on the impact of bremsstrahlung on electrons α = 0.01, 0.1, 0.2, 0.3, 0.5, 0.8

with constant term 0.005 for dotted
0.03 for solid lines





Under these circumstances and in the case of isolable charged particles there is about no place for calorimetry.

The case of electrons is different in view of the Bremsstrahlung.

The role of calorimetry should then be reduced to handling neutrals

if possible

PFA or the common sense

A calorimeter could then properly be called an “oudeterometer”.

some surprising consequences

In the competition between homogeneous calorimeters and sampling ones,

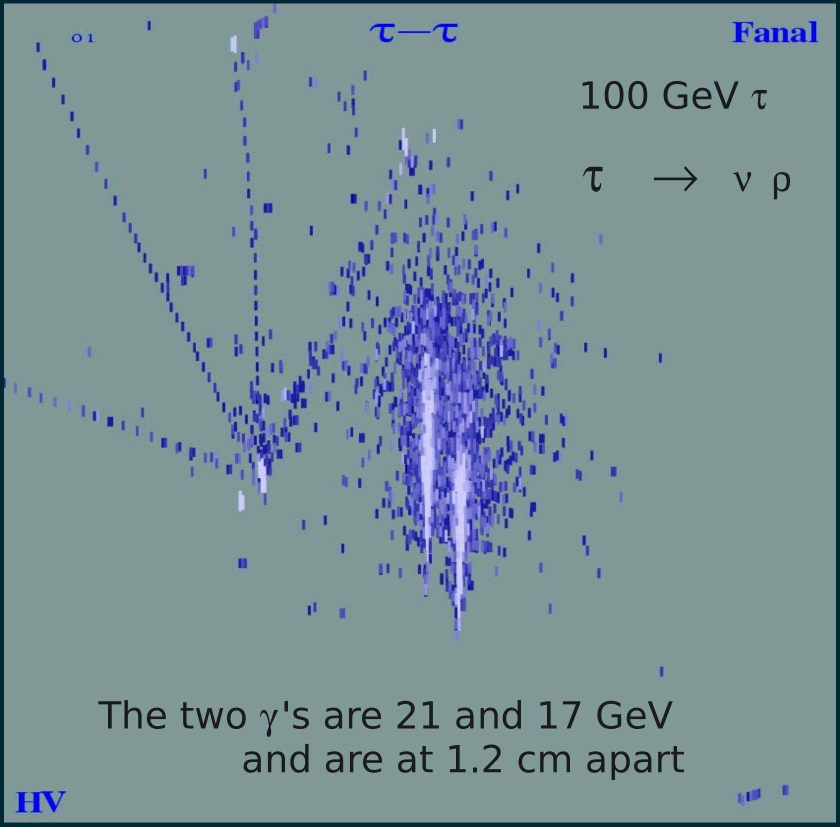
except in specific cases like rather low energies (Fermi)

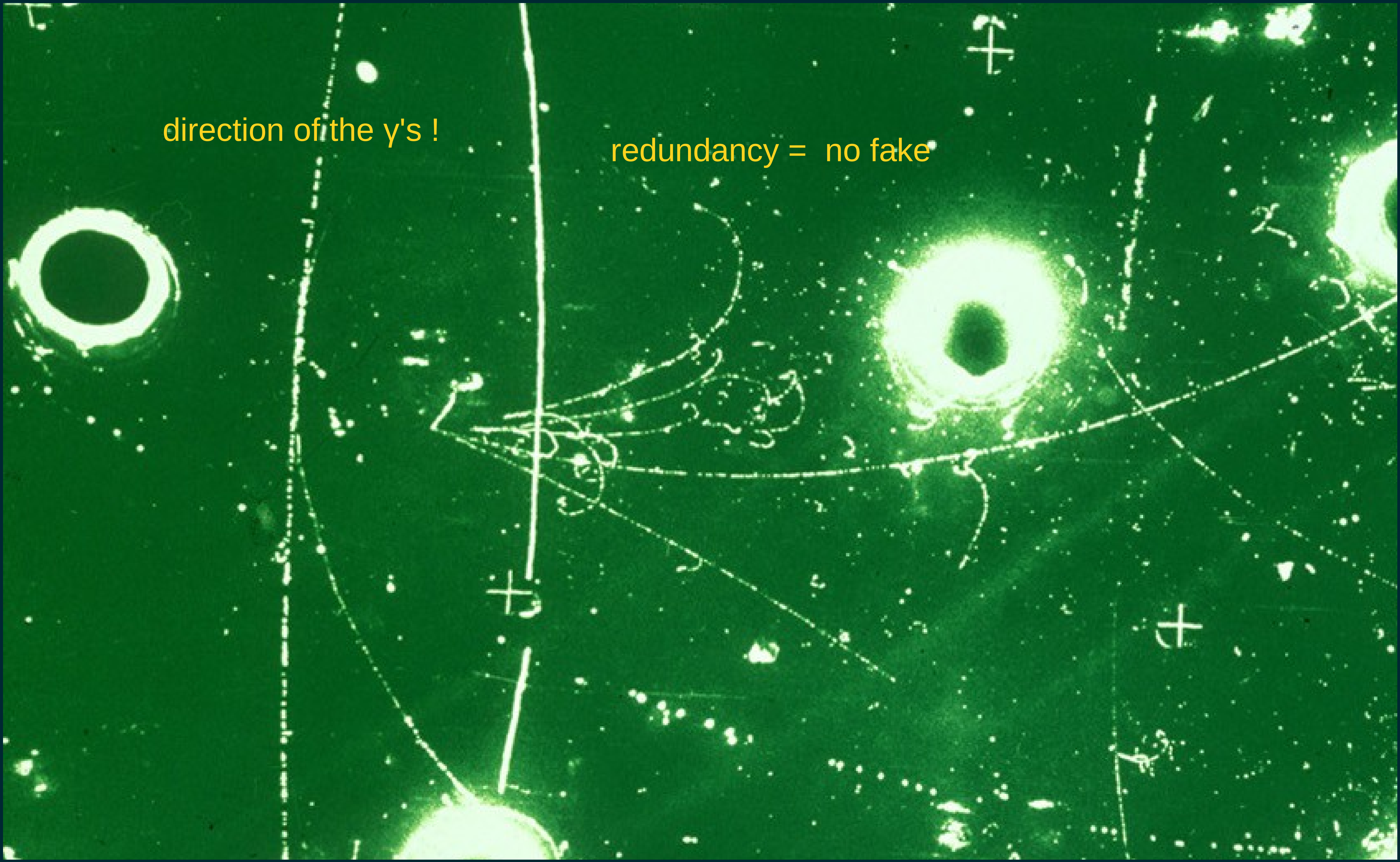
the sampling method will win on the basis that it has much more flexibility.

Making a clean, very granular
homogeneous calorimeter is difficult
almost self-contradictory
except some examples
Hl bubble chamber or SuperK

Constant term
measurement of the direction
confusion with adjacent showers

are easier to handle with fine grain




direction of the γ's !
redundancy = no fake

The constant term may have different sources
in electromagnetic calorimeters the main source may be channel calibration

Then high granularity may be of help : $Nhits \propto E$

under the assumption that after a calibration procedure the constants are random,
the fluctuation induced on a 100 hit cells shower will be reduced by about 10 !
and a trivial cell calibration at 5% generates a shower constant term of 0.5%.

The granularity has randomised the channel impact

provided there is no coherent effect !!!

along the same arguments

Impact of missing channels, leakage

If dead channels are reasonably randomly distributed
their impact on the energy measurement or others may be negligible

A simple view would be that the missing channels signal can be inferred from the neighbours

We can rely on the characteristic shapes
an inefficiency on the tracks within hadronic showers is easily corrected for

for a compact electromagnetic shower,
the expected shape depending on few parameters can be best adjusted on the existing information and the parameters obtained, a global adjustment.

For hadrons, tracks and el-mgn blobs are identifiable shapes even when the overall hadron shower shape is diverse. a local recognition.

The neutral hadrons leakage (in the rear)
may partly be handled by the analysis of the end of the calorimeter
but K^0s have some nasty tendency, when interacting, to produce leaading K^0s

The scales of the problem:

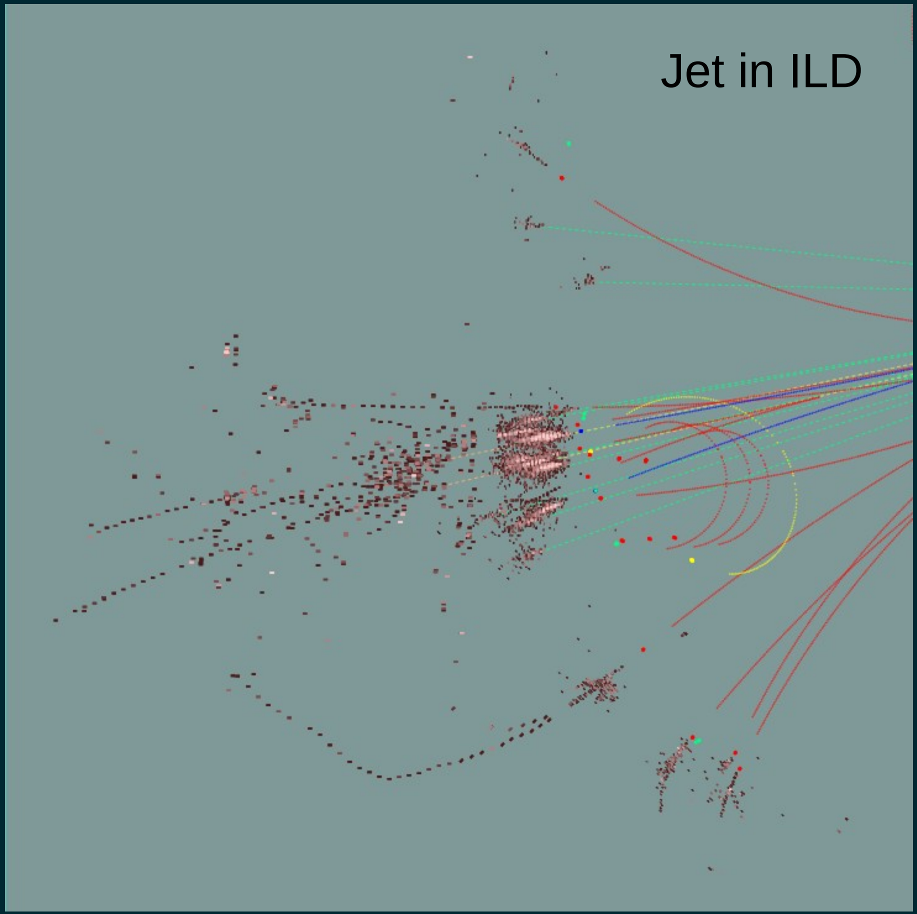
physics	the distribution of distance between particle impacts,
detector scale	the radius of the calorimeter, the field is not that important because it does not help forward
calo design	the radiation length, the interaction length,
extension of showers	the Molière radius, the showers shapes

From the processus of development of a shower
a shower looks like a tree (no loops)
but unfortunately with a fraction
of disconnected branches (neutrals)
and appears as an interesting fractal object.

Notice that the hadronic parts are wide
which generates confusion

but they are sparse and a fine study may
disentangle overlapping showers

all the art of the shower pattern analysis.



Today the hadronic calorimetry may offer more fun than the electromagnetic

I see 3 approaches toward the e/h problem

one is to make by construction e/h=1 by tuning the sensitivity to neutrons
or to electrons..
this was behind the use of U with scintillators (ZEUS)

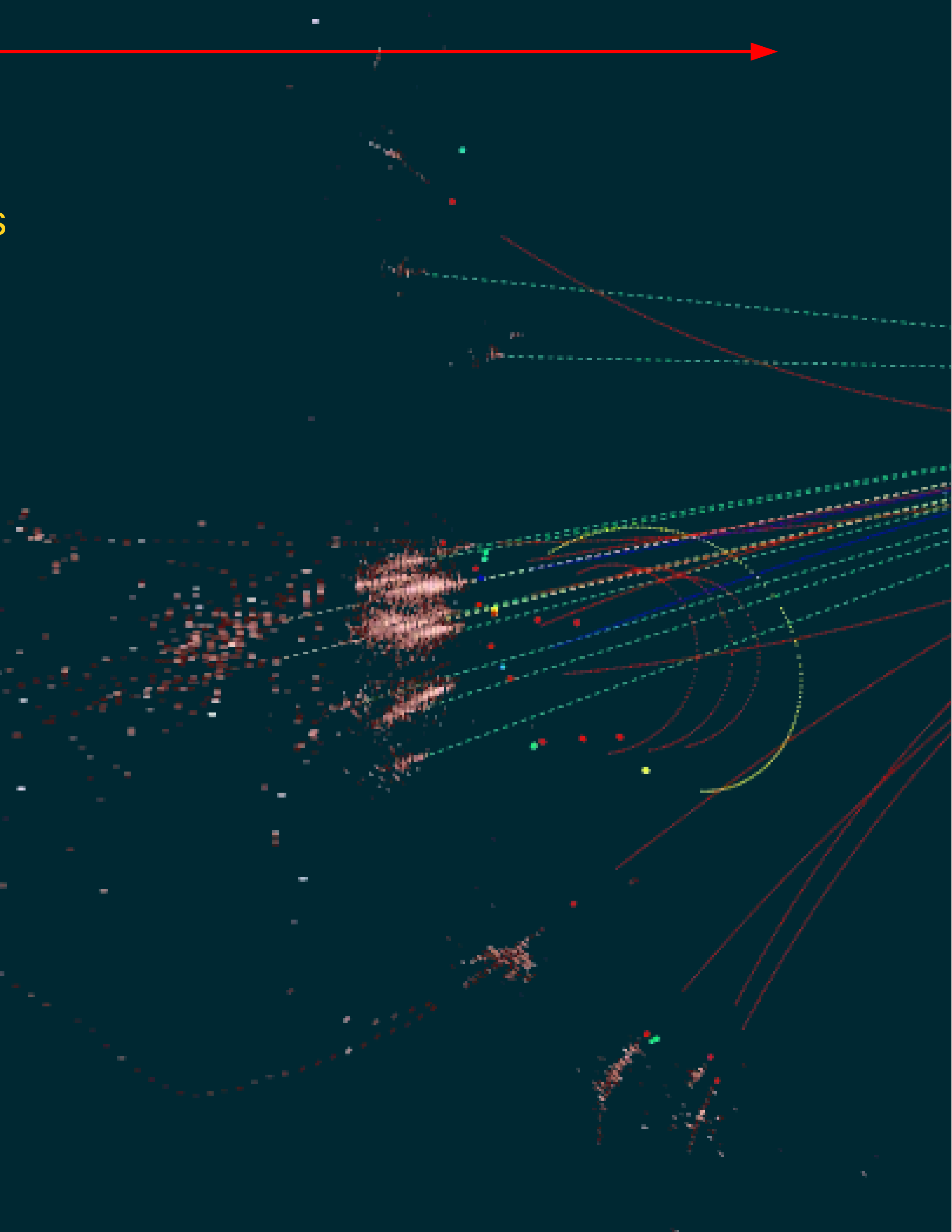
the second consists in having two measurements with a different local sensitivity
to electrons, the dual read-out

the third is to recognise topologically the electromagnetic contribution
in the showers and adjust the response

There is an attempt to the third solution in particular in digital calorimetry,
in that case there is an amusing interplay between energy and size of the cells

for a given energy there is a cell size which saturates adequately (in mean)
the response to electrons, unfortunately it depends on energy, this is
also apparent in the fractal dimension measurement.

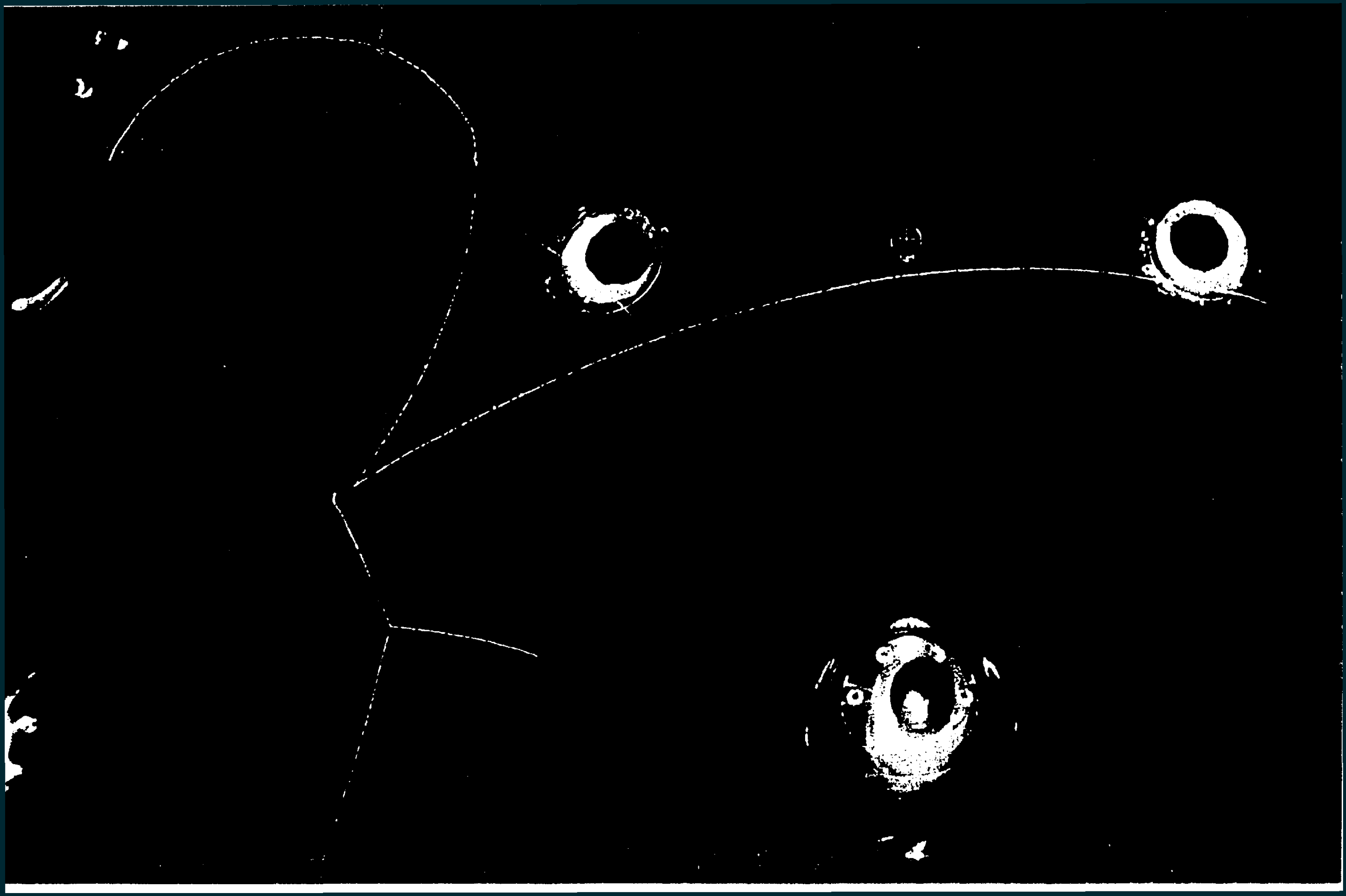
Looking again at these
it is reminiscent of heavy bubble chambers



but they were stereo images
providing a 3D with biased errors
plus dE/dx

when this may be 5D including
timing and local energy deposit
without speaking of it being a target
rate conditions
trigger, etc..

The future may have strong similarities
with the past, even ancient
but the technolgy evolves.



event in Gargamelle, the big heavy liquid bubble chamber, a tracker + a calorimeter
but at the time it broke, a calorimeter to be put behind was under construction !

The « classical » calorimetry follows a global approach
where the game is to develop a hardware providing as good as possible
an energy resolution.

Currently the trend is more toward an analytical approach (PFA) where
the topological properties are in a first step
handled independently of the energy side
they serve to separate and identify
then the energy is estimated reducing an energy bias.

Often, the existence of a generic method of analysis is assumed
and its realisation prone.

This is reasonnable at the level of basic tools
but the physics of what you are looking for
may have a strong impact on your methods
more than just a priori probabilitities

What I like in the PFA approach is not so much
its success in the energy domain under consideration

but the way it integrates an approach of the whole detector
for an optimum handling of information

a way to focus on the physics extraction more
than on the pleasure of making a neat piece of hardware

but I was surprised not to see
lepton in jet tagging or vertexing
included in what I heard.

It is remarquable to observe also the integration of software and hardware

In the past the quality of a calorimeter was evaluated in a simple way
where the role of software was that of a simple tool :
the observed single energy resolution being the α and the ω.

This is not true anymore,
the design is based on impressively detailed simulations
the reconstruction uses elaborate data structures and intricate algorithms
the analysis sophisticated approaches (MVA)

It is only through a thorough software development that the qualty of a design can be inferred.

and as there is no dearth of imagination
you can easily believe that the ultimate result will bring more than expected

Integration and the quality assurance

To reach the expected performances
in particular in terms of hermeticity, granularity etc..

the electronics is much more integrated (mix of analogue and digital)
but also completely embedded in the calorimeters and largely inaccessible

this is not a new trend but is more and more evident

There is no thing to be afraid of
the quality assurance has just to be carefully integrated in the project
like it is done for space projects.

We go from handkrafting to more industrial processes,
I am not sure it is an overcost but is anyway a guaranty of reliability

In conclusion

I do not care really about calorimetry!
but about a clever development of calorimetric techniques
integrated in a complete detector
plunging roots in the past experience
and resting on the most actual technological evolution.

There are revolutions which do not simply go back to the starting point,
they move to new worldsheets.

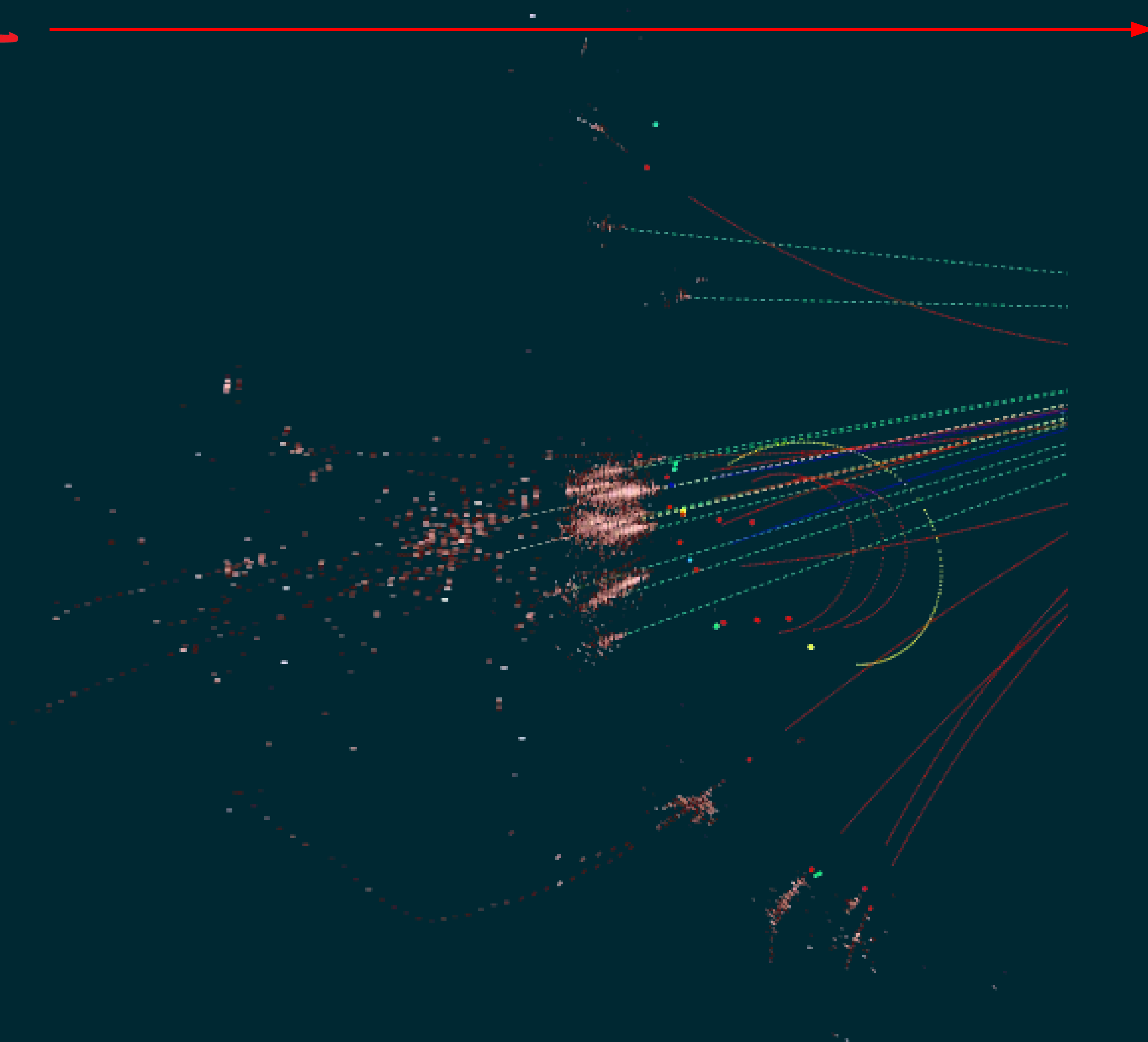
I may have expressed doubts more than certainties

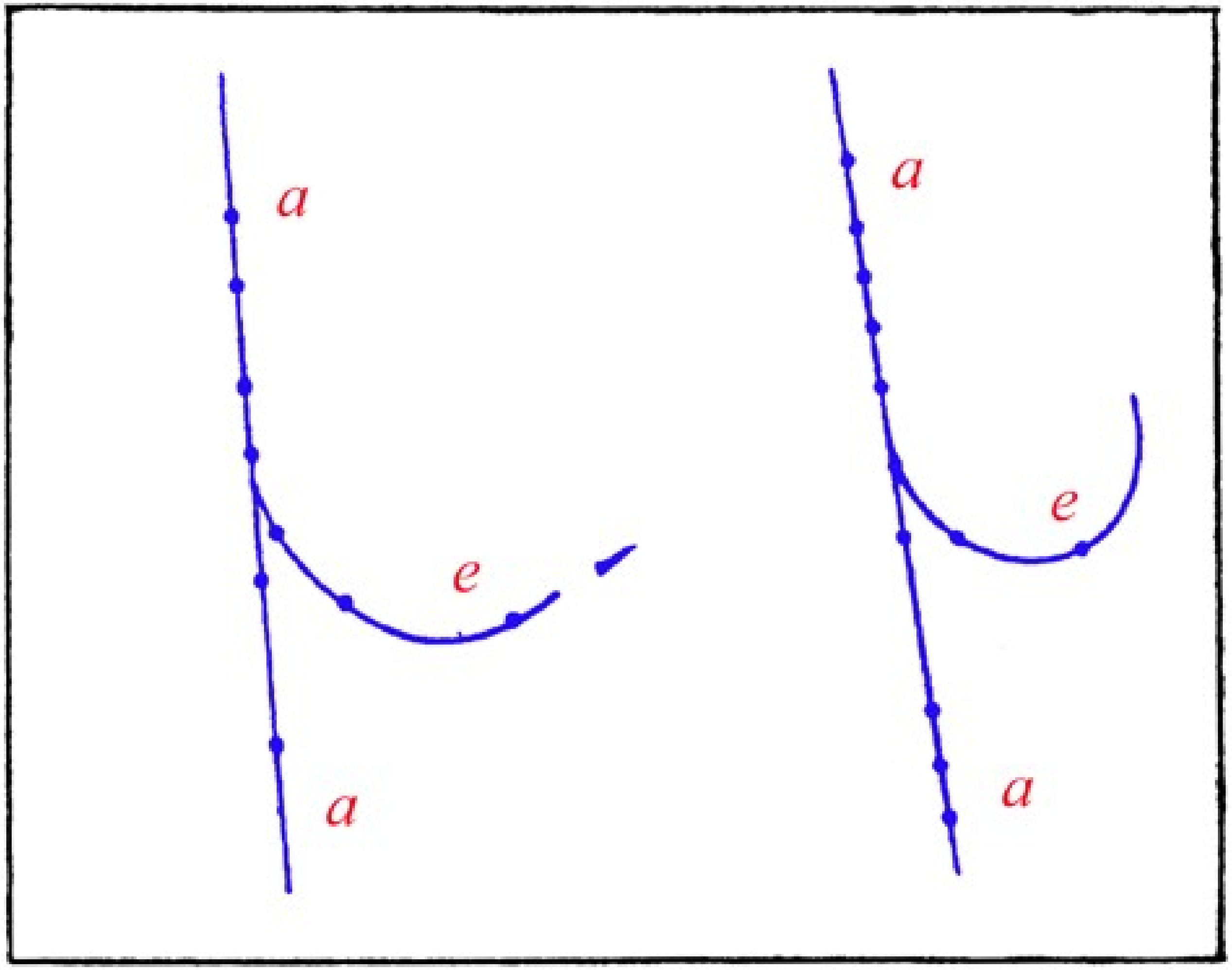
but is'nt that how science works?

END

I wish to CHEF numerous avatars in the years to come

in the sense of reincarnation rather than mishaps





Dessin stéréoscopique de la collision.