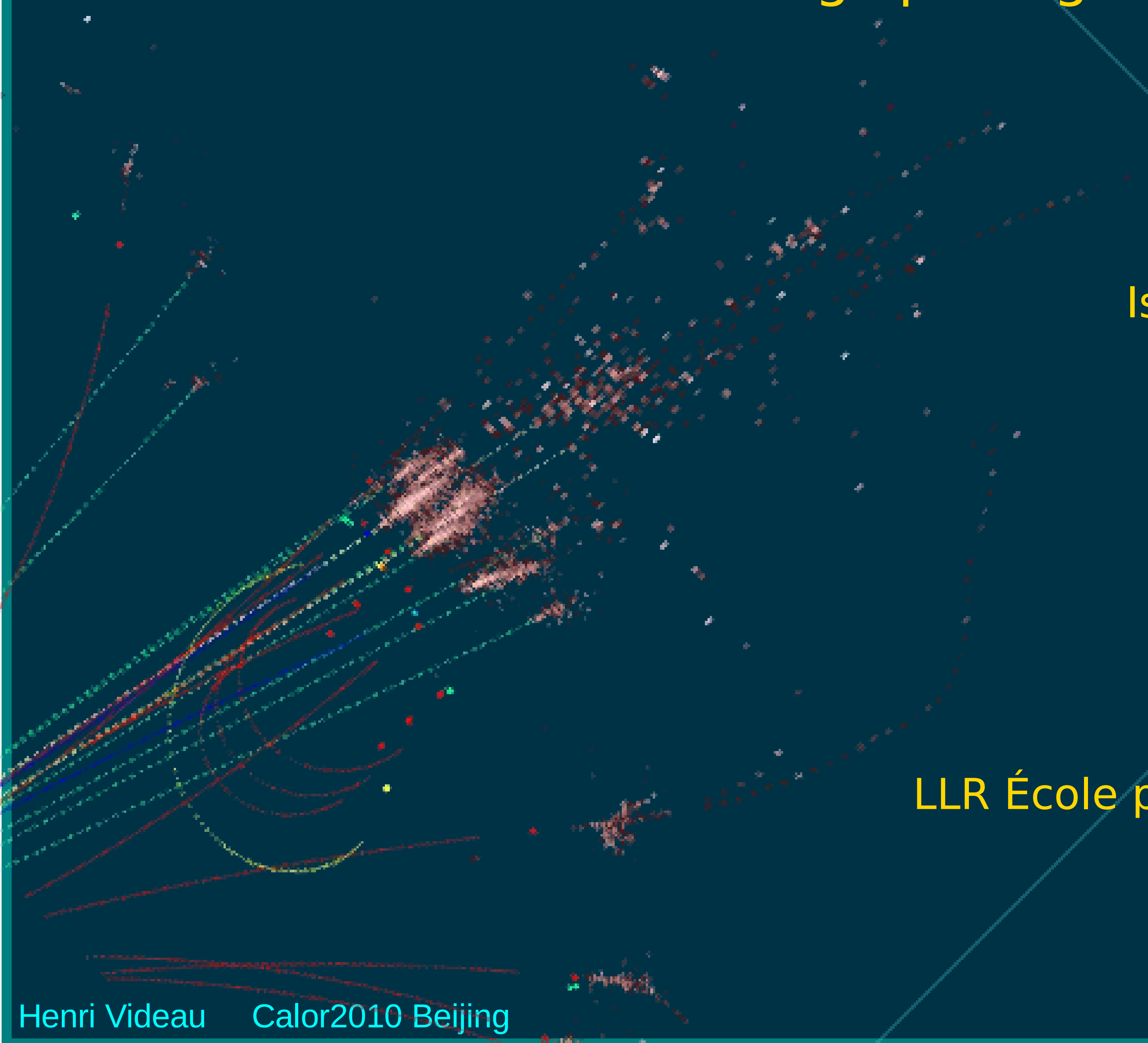
What does bring space granularity to calorimetry

or

Is n't calorimetry just a *pis-aller*?



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Introduction

With PFA in the back of your mind

The development of calorimetry for the linear collider
has led to a dramatic increase of granularity,
a factor 1000, ~30 longitudinal, ~30 transverse.

What accelerator/physics conditions
what technological evolution have enabled this?

What is it for?
Is there any future pursuing this way?
going to higher energies

Trying to figure out what does really provide granularity,

we can examine the role it plays in electromagnetic calorimetry,
then what can be expected on hadron calorimetry from the point of view of energy accuracy,
sensitivity to calibration,
leakage.

Conditions

Small grains implies embedding the front-end electronics in the detector

large integration in the front-end, self-triggering, digital storage.

huge multiplexing

Also for keeping the cost

An accelerator with a reduced uptime
may allow power pulsing,
hence reducing consumption and heat generation
in a 3.5 T field!.

Ensure quality of almost spatial level.

The purpose:

Looking for photons: measuring their energy, position, angle, number
Once identified in jets,
separated from other photons, from hadronic particles

Looking for electrons, identifying them, *measuring them*

A clear goal:

Making the pattern of photons as distinguishable as possible

Electromagnetic shower rather well characterised, up to fluctuations
tails and halo.
Cleaning the shower to its core while keeping resolution?
cluster, threshold

Importance of transverse and longitudinal granularity

For isolated photons the energy resolution is linked to sampling
≠ longitudinal read-out grain

the position and angle precisions are dictated
by the energy resolution more than grain
provided the cell size < Moliere radius

But in jets they have first to be found,
distinguished from near by hadrons and other photons

Then the measurement of the energy is done
after finding the photon.

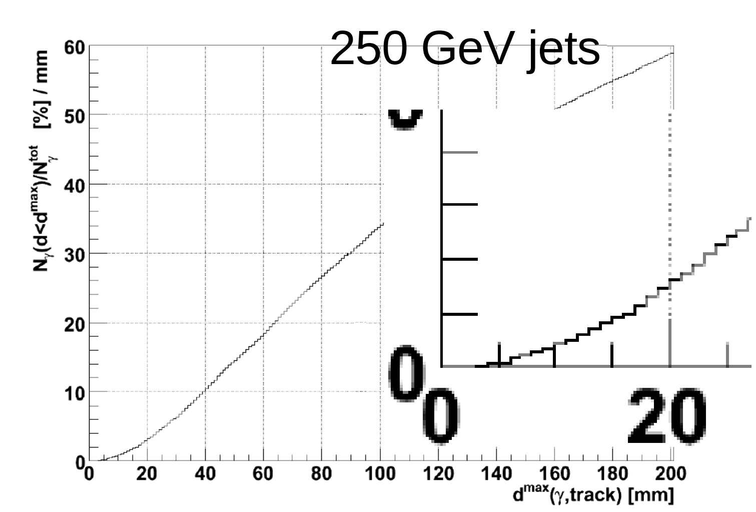
Separating from charged hadrons, (double counting in PFA)
from other photons

Separating two photons, why?
Find π0??

Valuable to sign the tau decays but up to what energy?

mixtures of photons can be misinterpreted as neutral hadrons
or charged left over

Probability ≈ surface, hence parabola



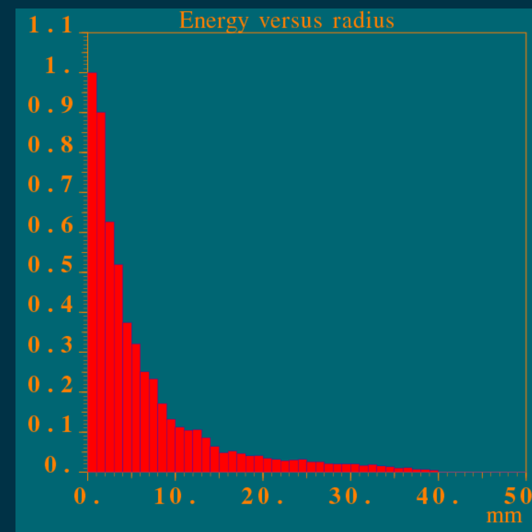
(a) Average fraction of the photons per event having a distance smaller than a given maximal distance d^{max}.

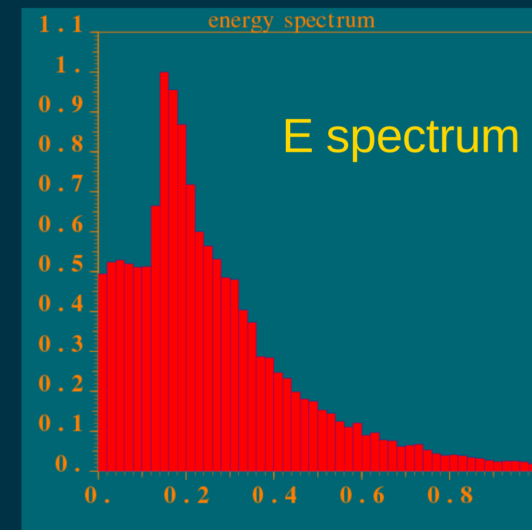
M. Reinhardt

Parameters to play with for shaping the showers

The radiator medium
The detecting medium
The sampling
The transverse grain size

The shape of photons is well defined,
The lateral distribution described by Moliere radius



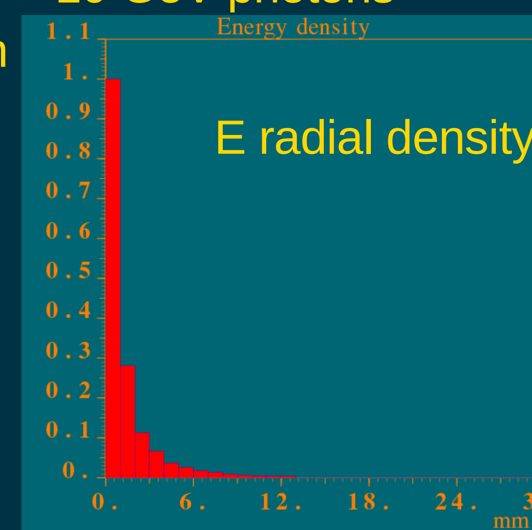


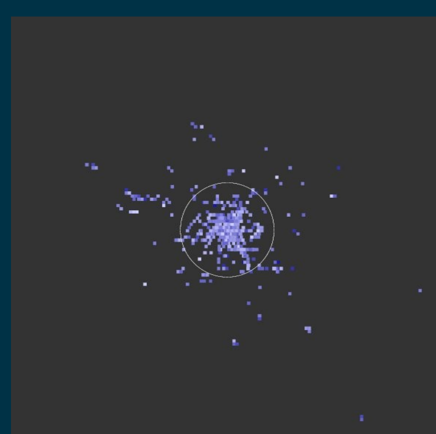
Marginal gain expected on M. radius:
Better material than W??
Play on detecting medium?
Thinner detecting system?
For a factor 1.5?

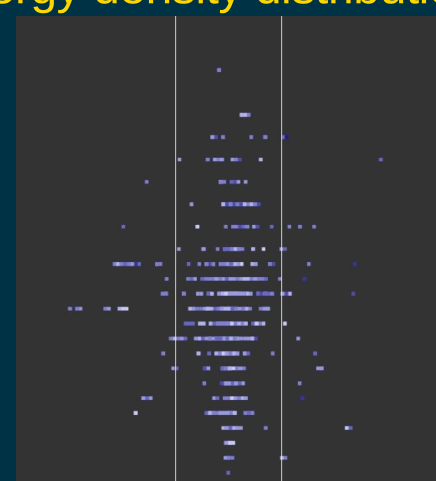
ILD ECAL W-Si 1mm²
10 GeV photons

Play with the grain size
And correlatively threshold

But rather look at the
energy density distribution





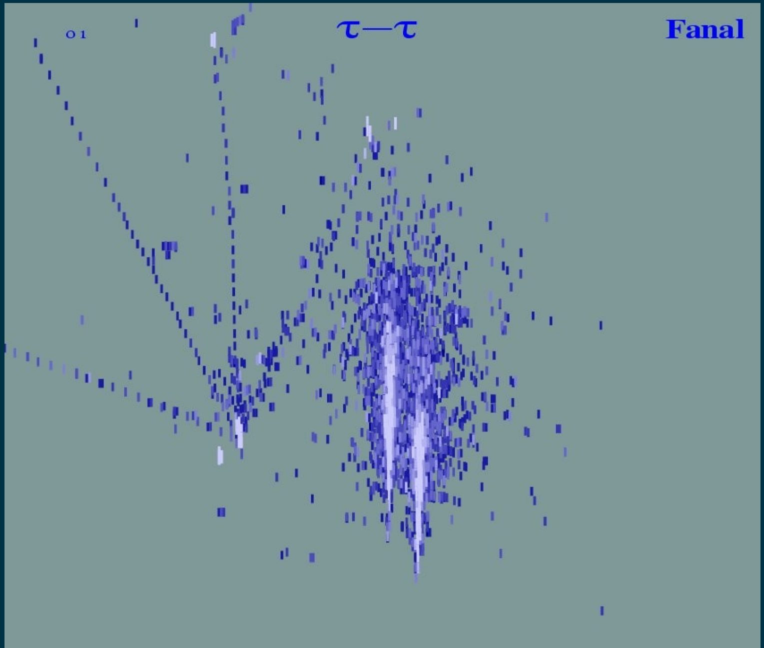


Separating close by photons

The core of photon shower is few (2-3) mm (ILD ECAL).

what is the probability that in a given domain of few mm²
at a given distance of the main photon
there be a significant fluctuation?

Have a cell size adapted to the core
Play with the threshold.



21 and 17 GeV photons 1.2 cm apart

100 GeV tau decaying into rho
seen with a 1mm² grain

Separating close by charged hadrons

The problem is to disentangle the photon from the track and its shower.
This to avoid losing the photon or doubly counting part of the hadron energy

1) the hadron interacts deep enough: recognise the track
2) it interacts close, sign that the photon blob can not point to the interaction
3) it interacts before the Ecal

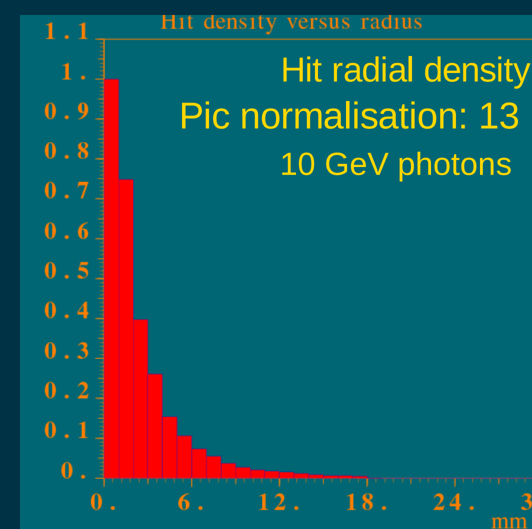
Charged tracks:
What drives the cell size is not any more the photon shape
but
the track shape

Cell size limit:
Track width due to multiple scattering!

10 GeV photon + 50 GeV pion

If a track leaves a signal in n layers before to interact,
what is the probability, as a function of the distance to the photon that this signal can be faked by the photon?

Trivial



Additional or miscellaneous

Caveat: interplay between cell size and dynamics

Position, (1mm/√E in ILD)

But if you can identify the start of the shower, (longitudinal grain)
you could try to profit from observing the conversion point (preshower)
If the transverse grain is good enough:
But 10 GeV photon position : 300µm !!!

$1mm^2$ pads ?

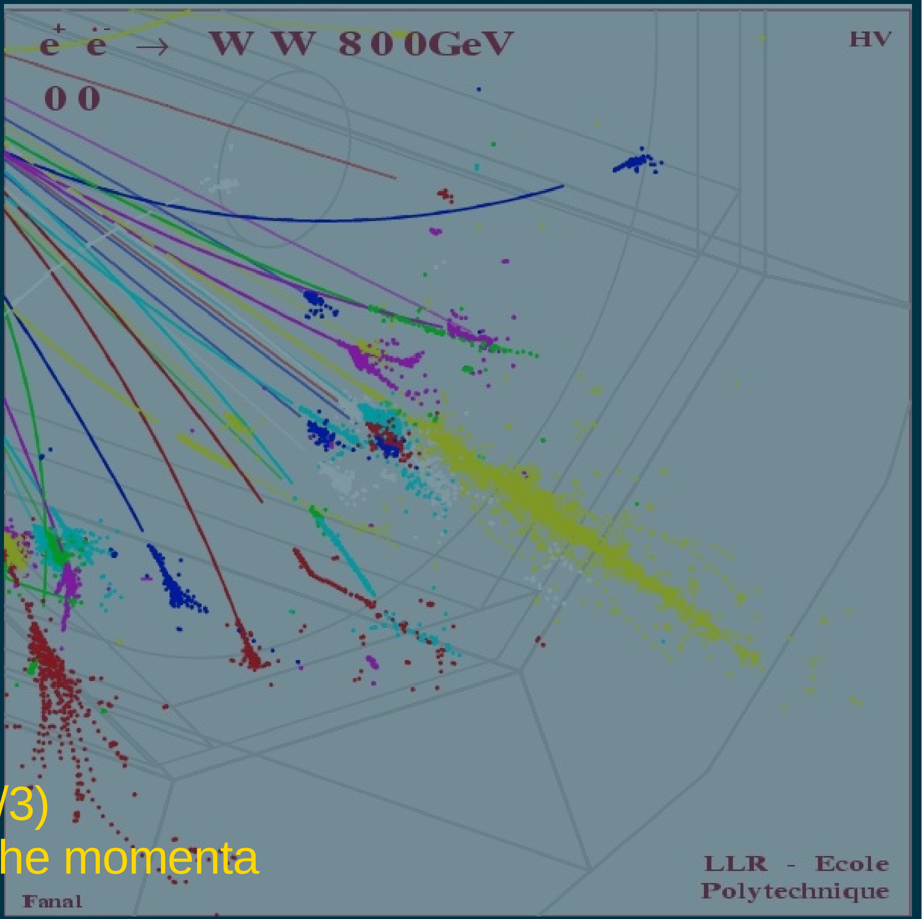
Counting cells provides an energy estimate, helps at low energy
What is the optimal cell size for “counting” the energy?
Doesn't it depend on energy?

toward MAPS?
Counting is meant to kill the Landau tail,
not get smaller than delta rays if staying digital.

In jets
How to disentangle neutral hadrons from the majority of charged hadrons showers?

Measure them at best, Resolution
Calibration
Leakage

Once you go clearly below the shower size (10cm)
the only relevant size is
the track size.



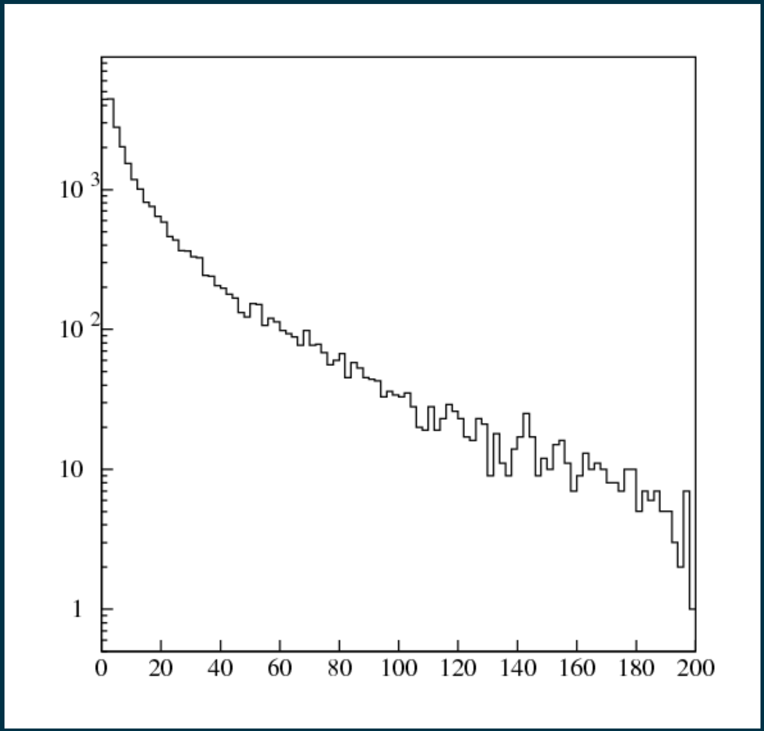
The idea: looking at tracks inside the calorimeter

Improve resolution by weighting (proven in AHCAL)
Improve calibration by picking tracks (efficiency)
Reduce the sensitivity to efficiency and multiplicity
Improve separation by following the charged links (2/3)
Improve the leakage (and resolution) by measuring the momenta

Knowing the neutrals produced at high energy (1 TeV CM)

500 GeV jets of any kind but tops, produced through a Z without radiative return

10000 jets



8% above 100 GeV!

Energy spectrum of the neutrals, K0, n

What about leakage of those?

By courtesy of JC.Brient

Elements of a solution?

To reach a sail through of 0.1% needs 7 interaction lengths (including 1 from ECAL) essentially independently of energy

In an interaction in the calorimeter few particles fly away, mostly charged ones

The probability of a second level neutral escaping 7λ is about 0.8%
Then globally the energy lost by leakage is little if no other source.

If a charged track escapes, we know it, we may measure it!

We are in a strong field, high energy tracks do not scatter that much.

Why not use your fine grain calorimeter as a tracking calorimeter?

This was already done in Aleph with the return field for μ identification

This is also a way to calibrate in situ

Have a look at 20 GeV K:

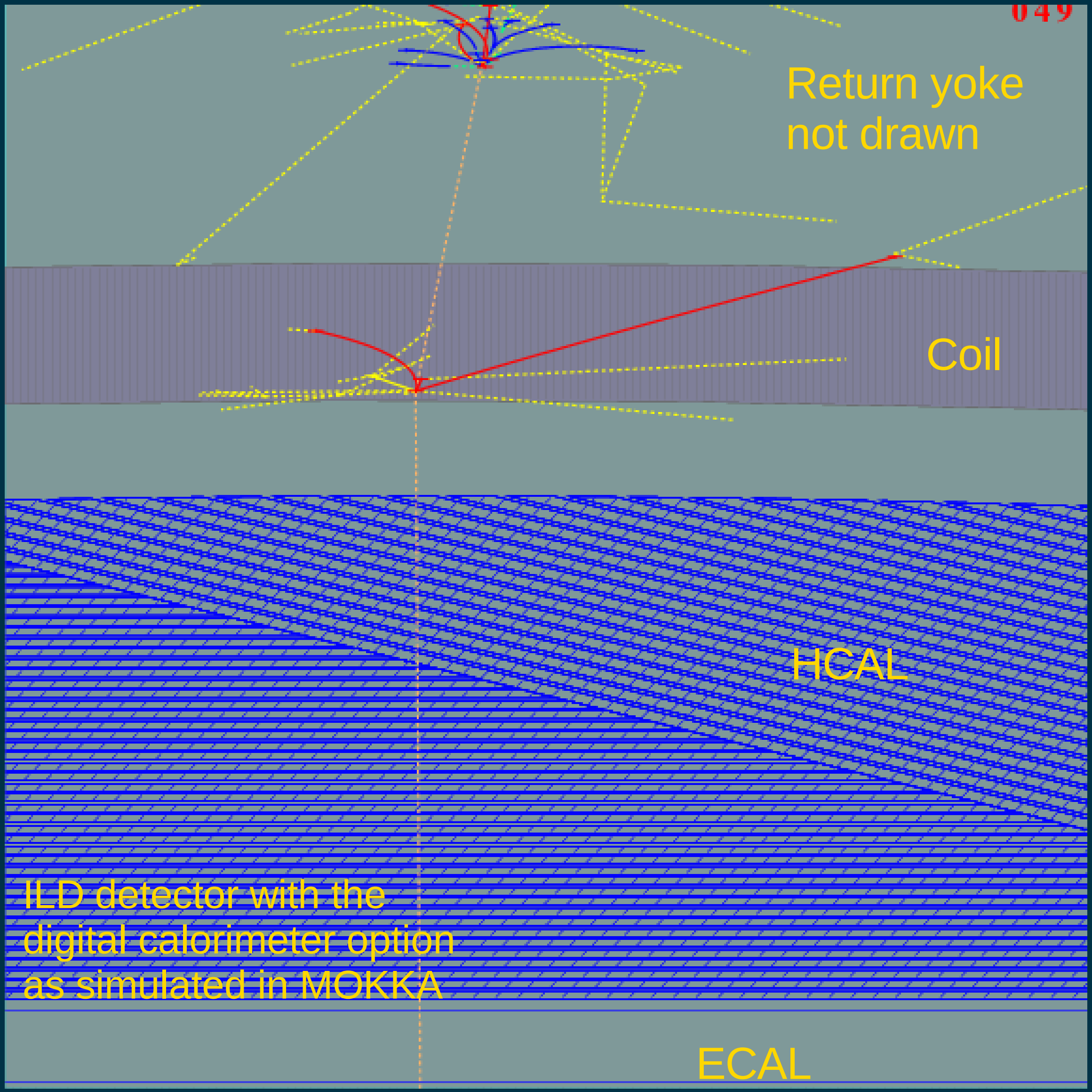
K^0_L sailing through

1/1000

Not much to do except

deeper calorimeter

or sign by tail catcher

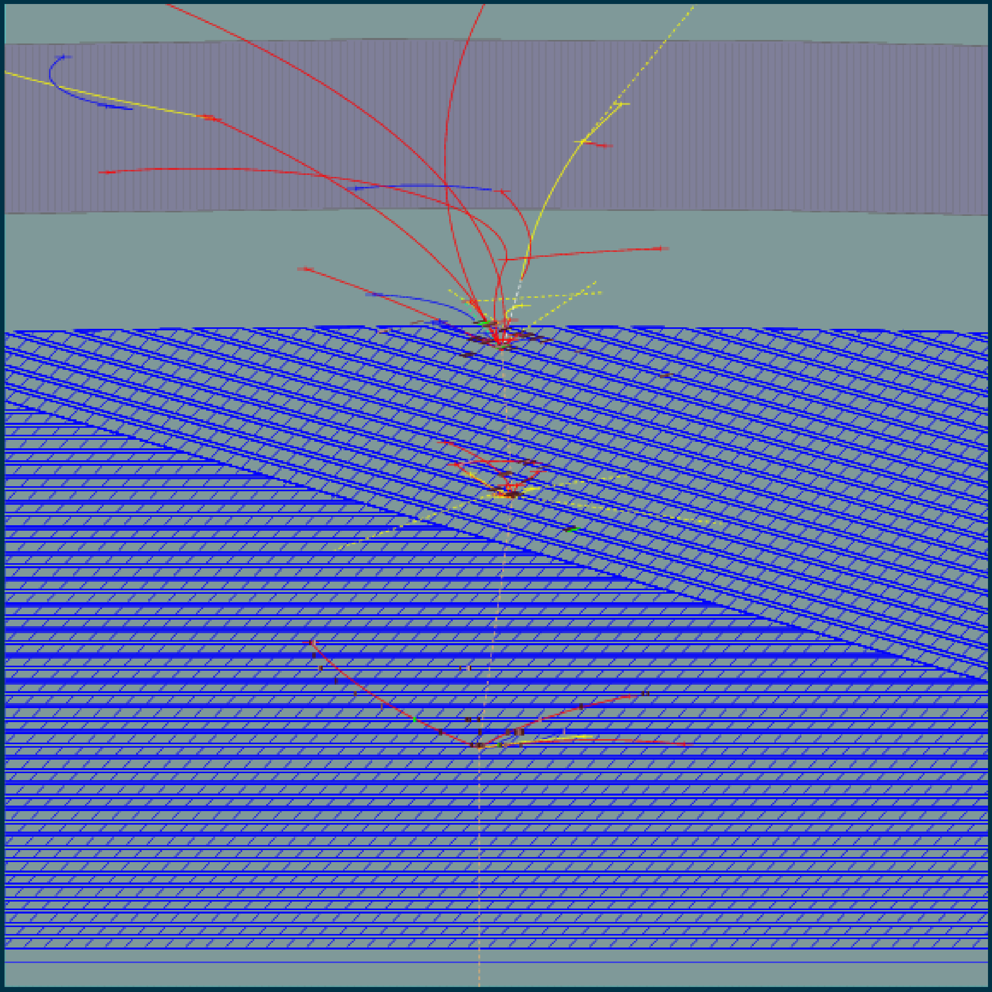


Beware: affinity in x >> in y

Test corpus:

1000 K^0_L 20 GeV

Third level neutral almost escapes



Those leaking more than 500 MeV excluding neutrinos make
6.6%

The fraction of energy lost should not be too dependent on energy

Measuring the charged particles momenta

In this example

the energy leaking (14.5 GeV) can be recovered by measuring the K momentum

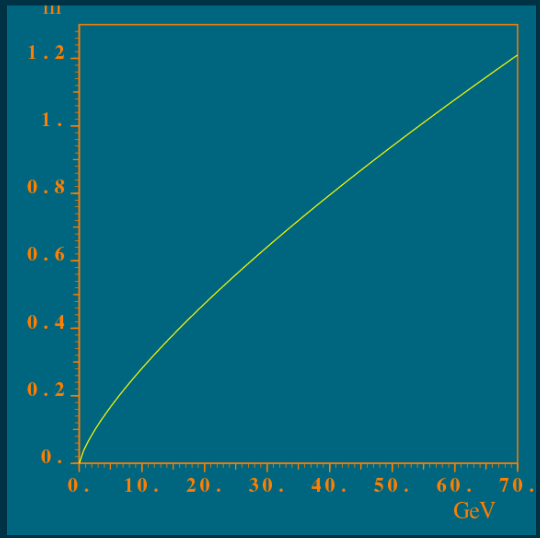
at better than $\frac{0.3}{\sqrt{p}}$

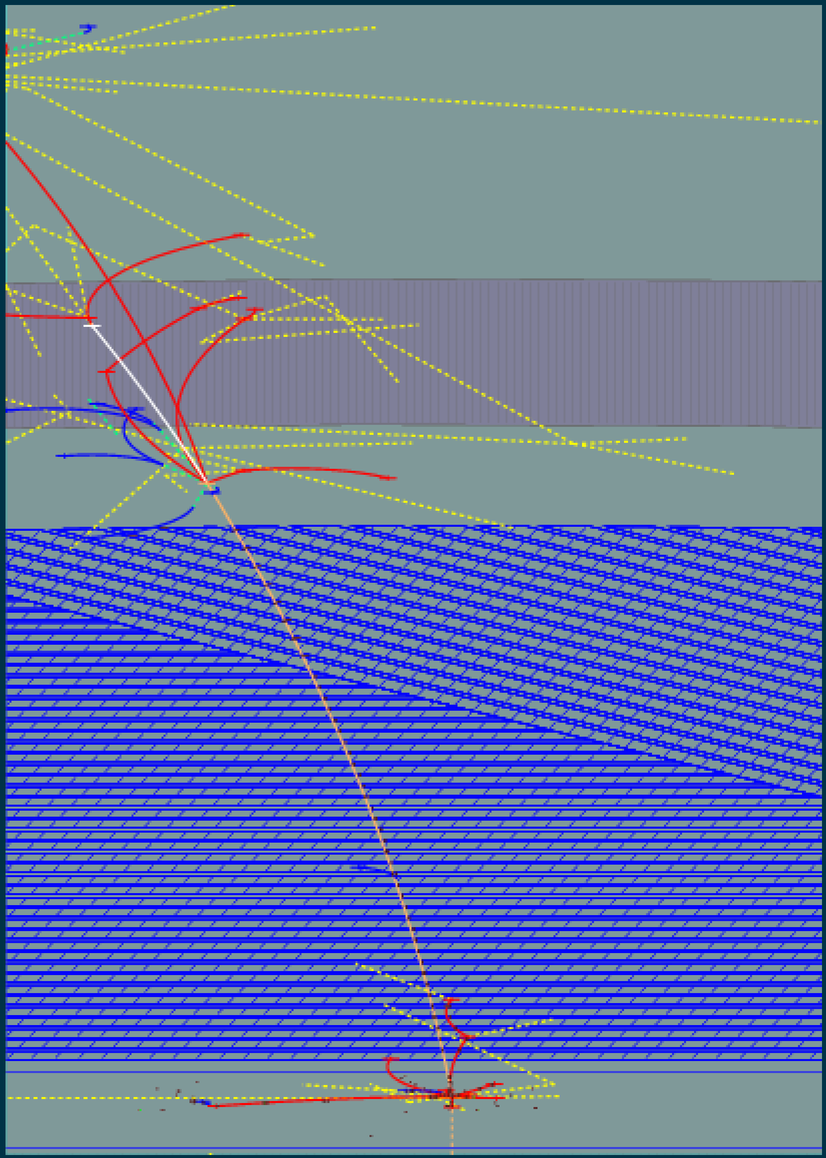
with p in GeV

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

Sagitta precision (δs) ~ 0.1mm
for a point precision of 0.3mm

$$s = 0.33\,10^{-3}\sqrt{p} \qquad L = 0.05\,p^{3/4}$$





Care about internal alignment!

Tracks leaving the HCAL can be measured, relieving their leakage

Tracks long enough and generating an interaction in the calorimeter can be measured and this improves the calorimeter resolution

In our corpus 4% saved by fitting tracks leaving:

2.6% of the K^0_L have a leakage larger than 2.5%

Note: this needs a more careful treatment
the method used here was, say, heuristic,
It involves a huge effort on analysis.

Conclusions

A fine grain calorimeter provides the opportunity
to disentangle finely the different components of the jets
and of the showers (resolution).

This provides a way to monitor the detector in situ, to palliate inefficiencies.

Placed in a high field it may provide an adequate measurement
of the momenta for charged particles.
This may help reduce the leakage
mostly in the barrel.

The ILD calorimetry brings an adequate response in the energy domain
currently under investigation

Going to millimetre size
may permit to improve
and to keep the resolution and the leakage
at higher energies

Why not go for a real tracking calorimeter !

Warning

Do not ask me about the technologies even though it looks feasible for DHCAL
nor about the software effort!

Just to try to see if this can be a meaningful challenge