Calorimetry: the art of compromises

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Defining a calorimeter

Array of identical absorbing detectors.

Single particle measurement

Simultaneous information on :

- Energy
- Position / direction
- Time
- Particle type

Moderate/good resolutions
Large acceptance
Limited volume
Stability

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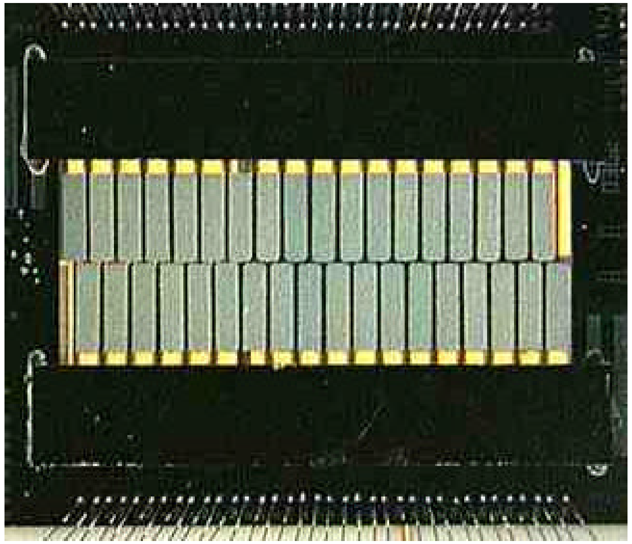
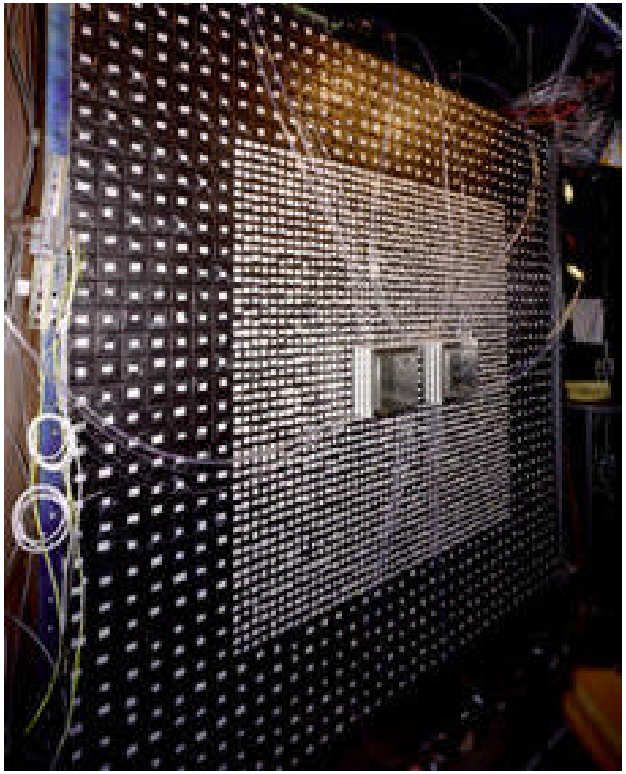
Spectrometer:
High resolution in one variable
low acceptance
bulky

The calorimeter invasion



XQC : 4 mm x 9 mm
20 to 1000 eV



KTeV CsI : 2mx2m
2 to 100 GeV

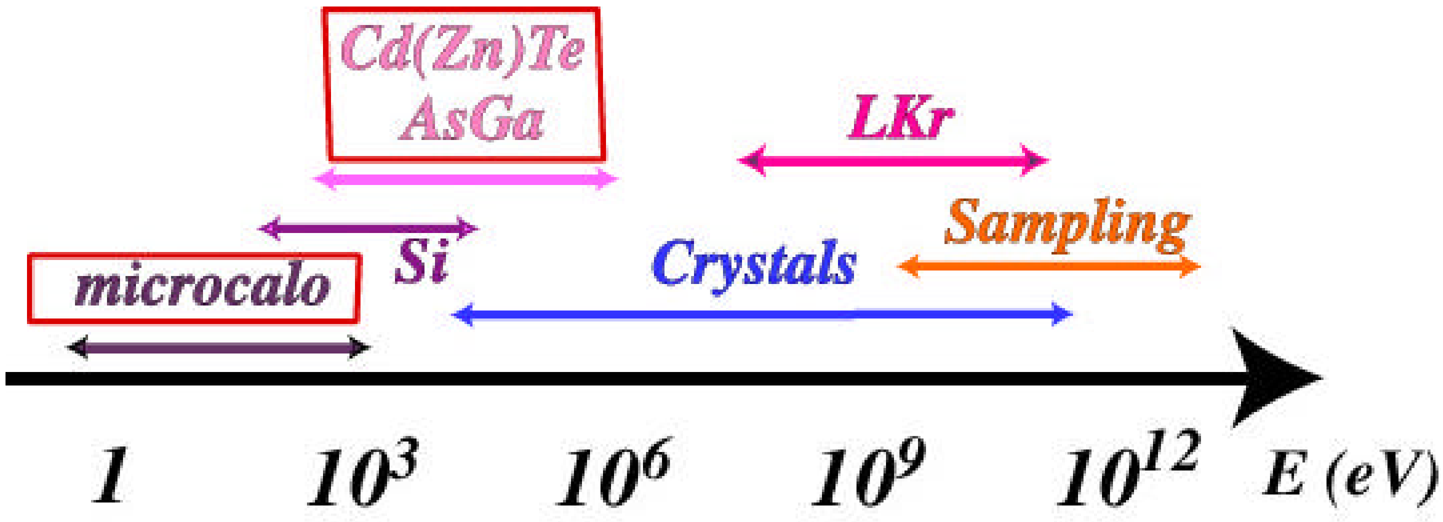
New territories: photon detectors

High energy physics : done

Astrophysics: spectrometers -> calorimeters

Low and medium energy photons : new detection schemes

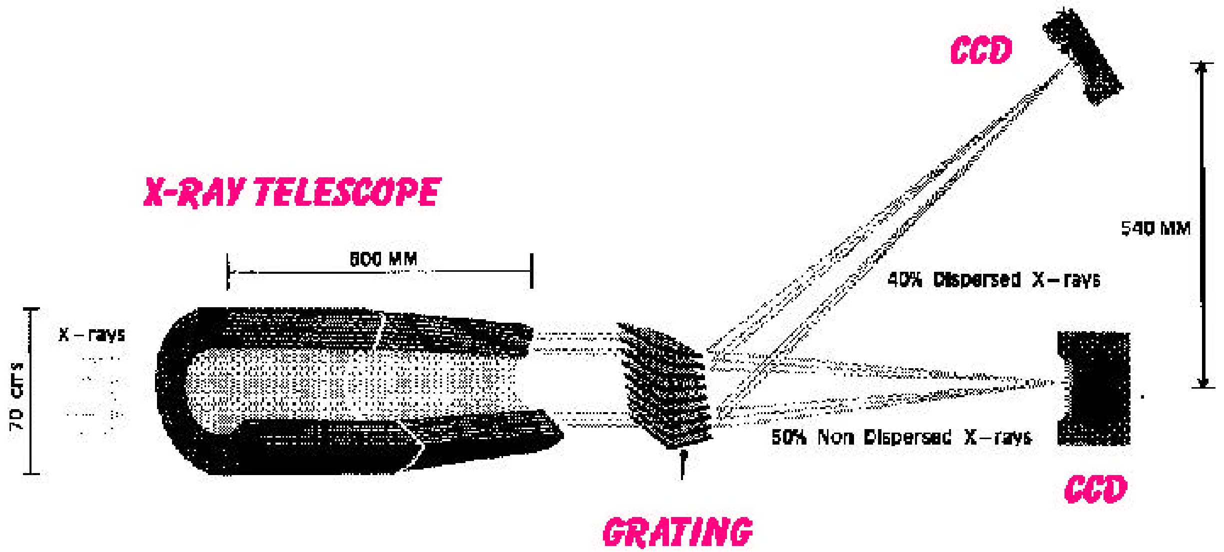
Photon detection with "calorimeters"



Example: Astrophysics X-ray detectors :

Photon detection 200 eV to 10 keV
grazing incidence telescope: big aperture

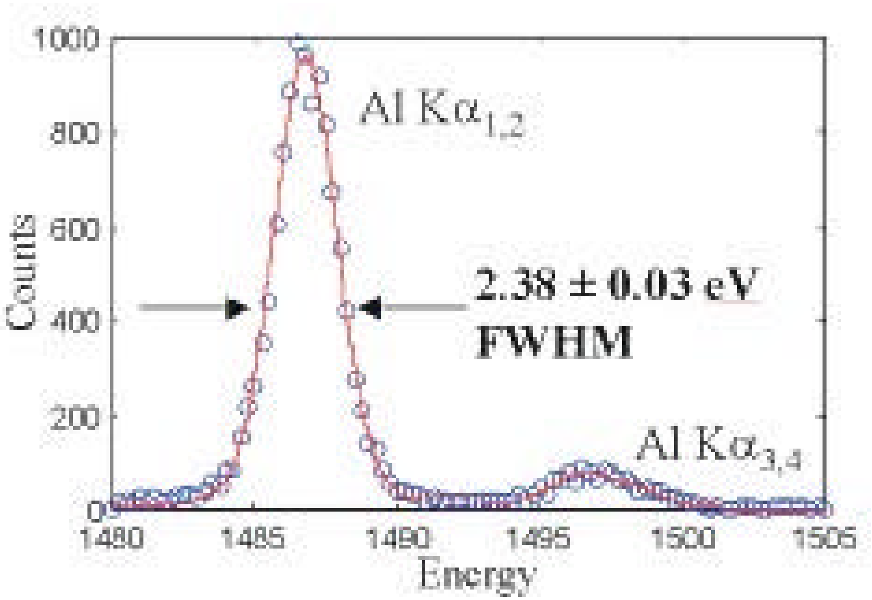
Present focal plane : grating + CCD (ex XMM, launched Dec 1999)



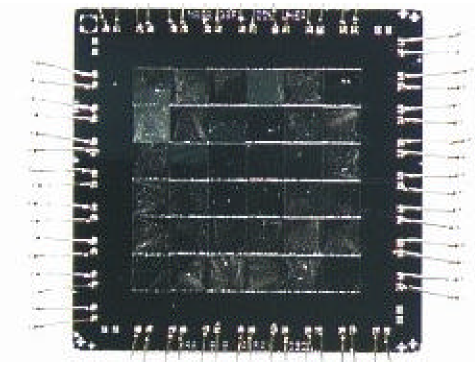
Next generation X-ray detectors: Cryogenic microcalorimeters :
almost same resolution, (without grating) with pixel imaging.

First attempts: XQC (balloon), XRS on ASTRO-E [:(failed launch]

Future : Constellation-X



Best lab resolution: 0.16 % at 1.5 keV
Transition Edge Sensor



6x6 pixels,4x4 mm^2

HgTe absorbers, 65 mK

12 eV @ 6 keV

Same stream of technology as the bolometers for WIMPS

Another recent field : room-temperature semiconductor X and gamma detectors

10 keV to 1 MeV : Medical imaging , astrophysics, material analysis

Usually: difficult choice between imaging (position) and E-resolution

Many techniques used (film, xenon gas, ceramic scintillator screens, CsI needles, …)

Good stopping power
Good E-resolution
Pixellized
Solid-state

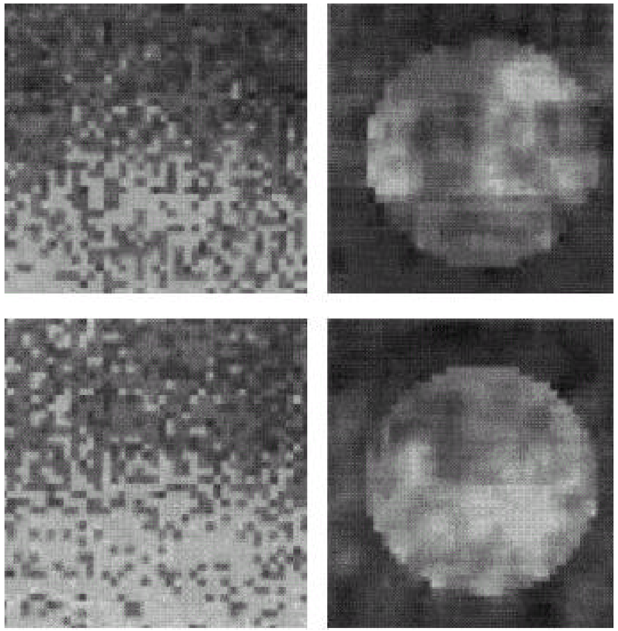
Recent devices : GaAs or CdTe pixel arrays
a real X-ray calorimeter

using HEP pixel technology

Example of pixel X-ray photon counters

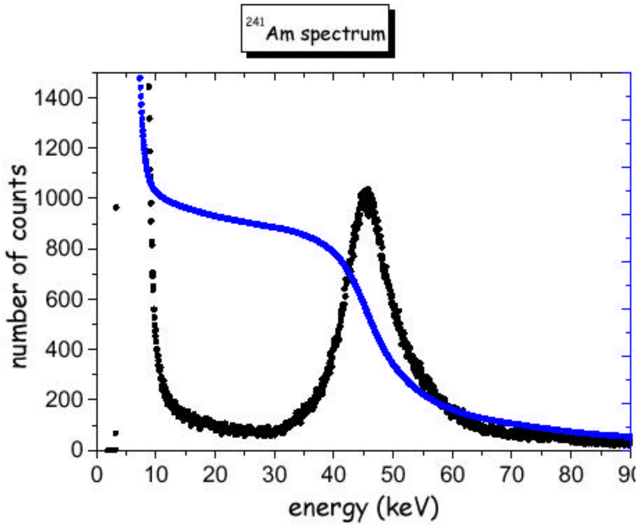
GaAs 64x64 pixels (170m)^2

bump-bonded to MEDIPIX chip (CERN+INFN)



Film digital

Mammography phantom



Alenia Detector
600 μm thick
170 μm pixel size

Photon calorimeters : the full range

Which energy resolution is needed ?

Visible, UV **X** **Gamma**	***Spectral lines*** **Atomic** **Nuclear** ***Imaging***	**Competition with dispersive spectrometers** **Background reduction** **Differential imaging**
Hard gamma astrophysics	***Continuum sources*****:**	**Prefer angular resolution**
Particle physics	***Narrow states***	**p^0, K^0, B-physics**

Less stringent at high energy colliders : LEP , G(Z) = 2.7%

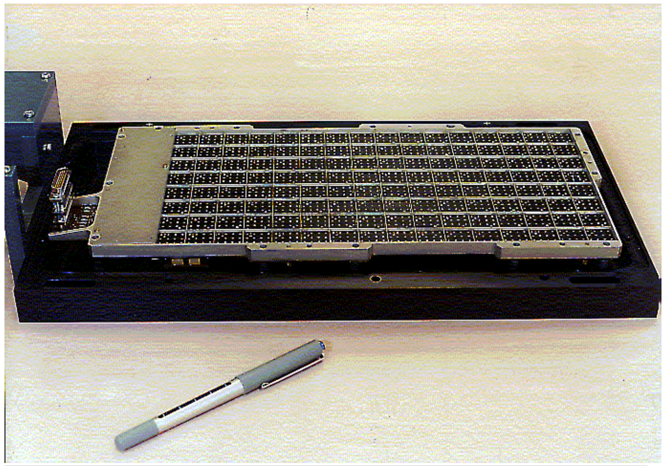
Exception **: LHC:** **G(H) < 1% for M_H < 270 GeV**

Example : Integral satellite

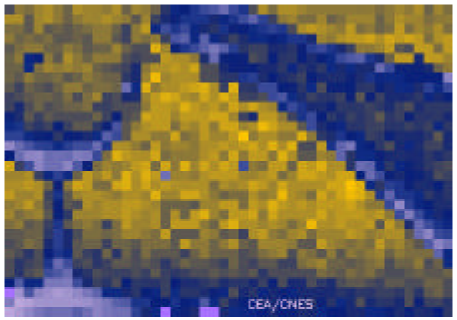
30keV to 10 MeV photons

SPI = 19 big Ge(Li) for finest energy resolution (2keV @ 1 MeV)

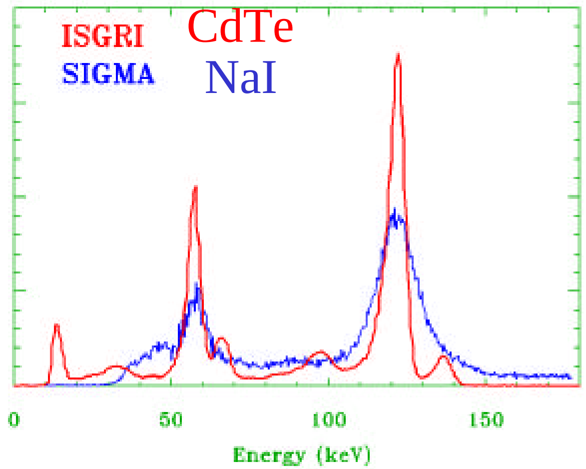
IBIS imager = CdTe plane 128x128 pixels in $(60cm)^2$
+ CsI plane 64x64 " "



1/8th of the CdTe detector



Imaging...



Spectrum

Angular resolution on photon measurements

Of course crucial for astronomy

Low energy: telescope => angular = position resolution at focal plane

Visible : fraction of arcsec ; low-energy X : ~10 arcsec (XMM)

Hi-X , low gammas : coded mask :

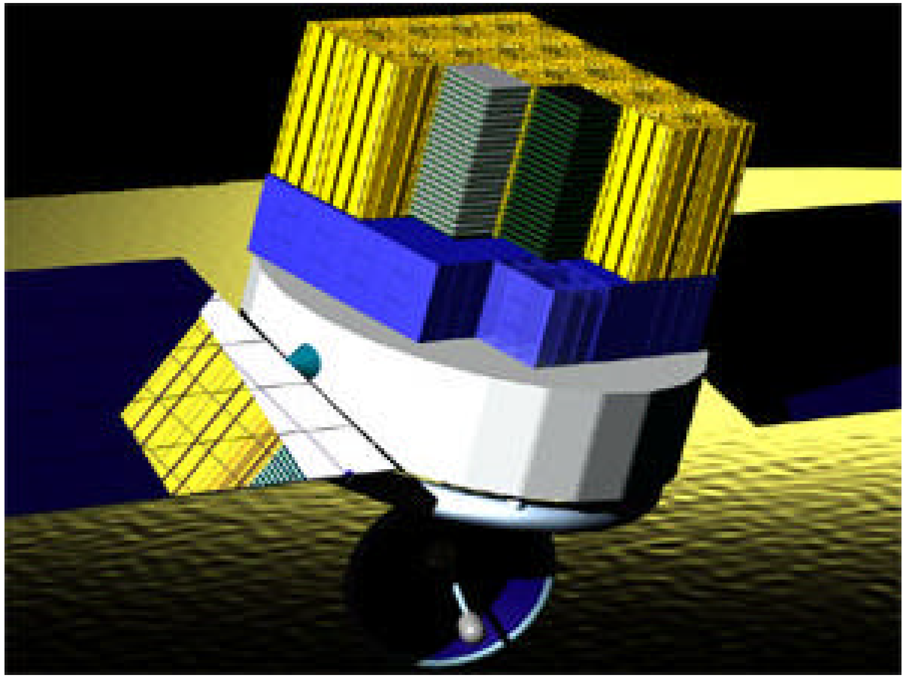
~ 10 min (Integral)

Beyond 10 MeV : gamma conversion

Directly opposing the compactness of calorimeters!

Limited at low range by multiple scattering

Photon direction measurement by calorimeters

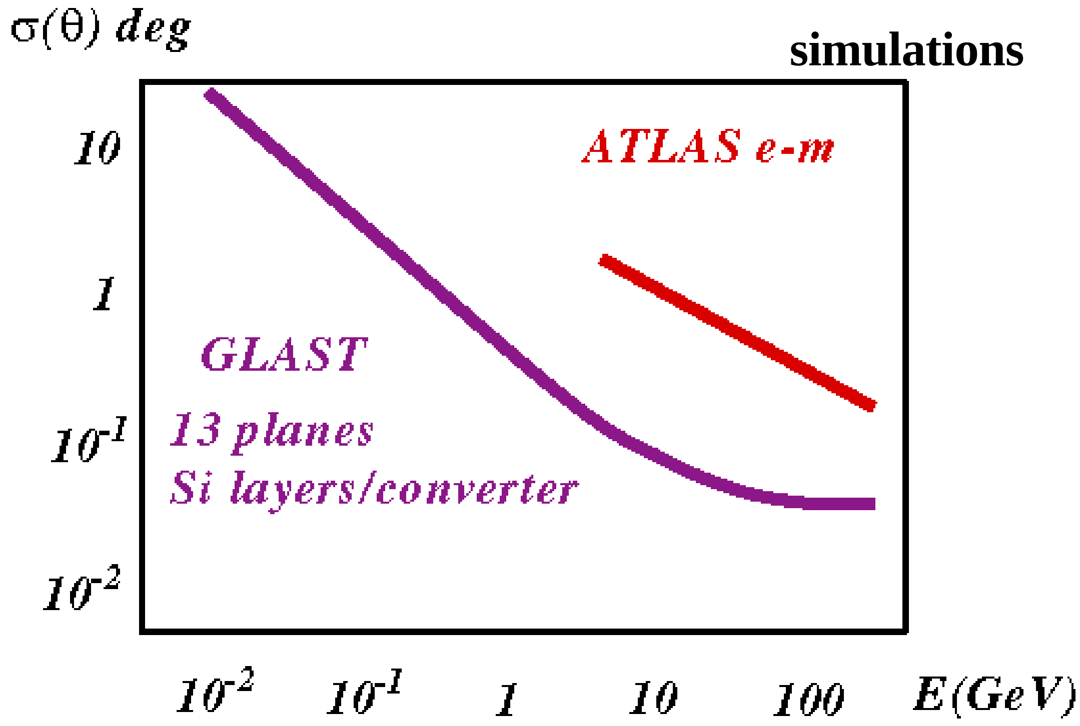


GLAST satellite: conversion tracker (Si strips)+ CsI calorimeter

ATLAS e-m calorimeter segmentation for Higgs -> g g

...Photon direction by calorimeters

1 deg at 100 MeV: a challenge!



Also interested: K0PI0 exp^t at BNL (CP violation from K^0-> p^0 nn , BR = 2 10^{-11})

K^0 vertex reconstruction: g from 200 to 500 MeV: 60 preshower planes (!) in 1.5 m resolution similar to GLAST.

Granularity: acceptance vs pixel size

- position resolution, imaging capability

- background rejection, particle identification

At low energy: **impact size small => limited by the number of channels**

Power consumption (space applications)

Cost

Trade-off with homogeneity

At high energy: **usual transverse scale : Molière radius = a few cm**

But much more info available.

=>preshowers, special segment : NOMAD, D0, CDF, CMS, ATLAS,...

fine granularity in depth ALEPH, DELPHI

Tungsten/Si project at future linear collider?

Homogeneity with many channels ?

Carrier production and collection

Photons (crystals): several %

Charges (semicond, ionization)

often less than 1%

(Phonons (mcalos) ??)

Part is generic.

rule of thumb: keep simple

Carrier count calibration

Light

Electronics

CMS

ATLAS

Low cost, reliable, 1 per 1000 precision

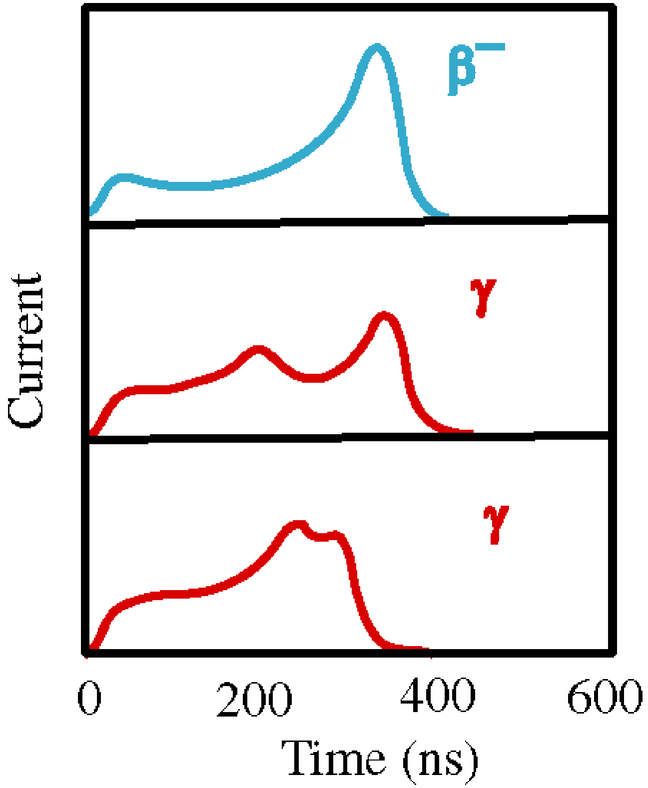
electronics calibration is yet to come...

Strong dependence on available physics signals for calibration

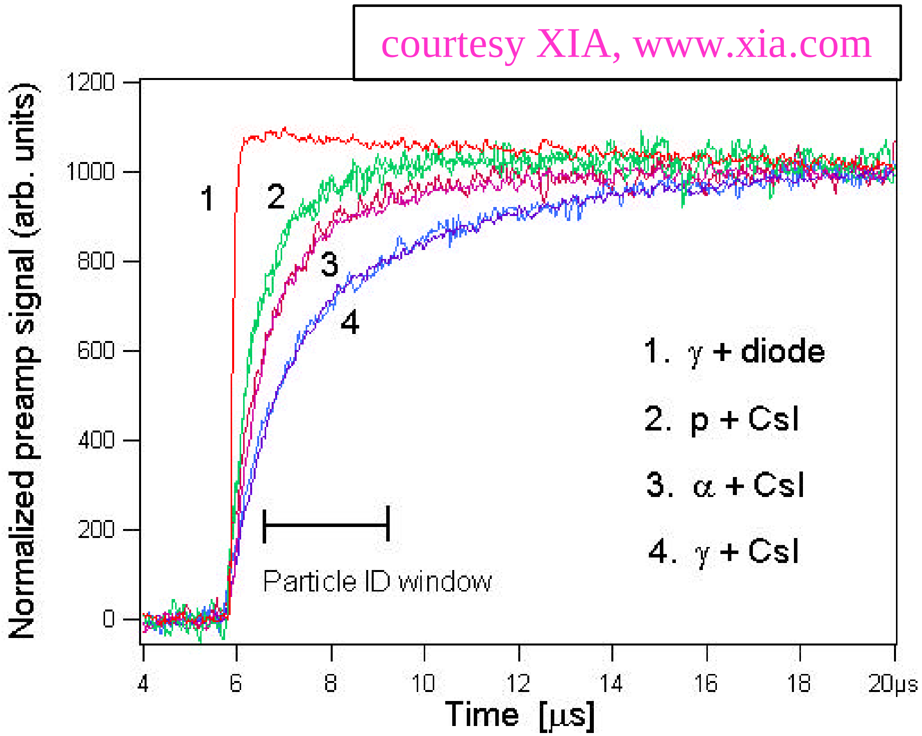
Sources, on-line beams, masses (p^0 to Z^0)

Particle identification and isolation

Low energy: identification inside one pixel => Pulse Shape Discrimination



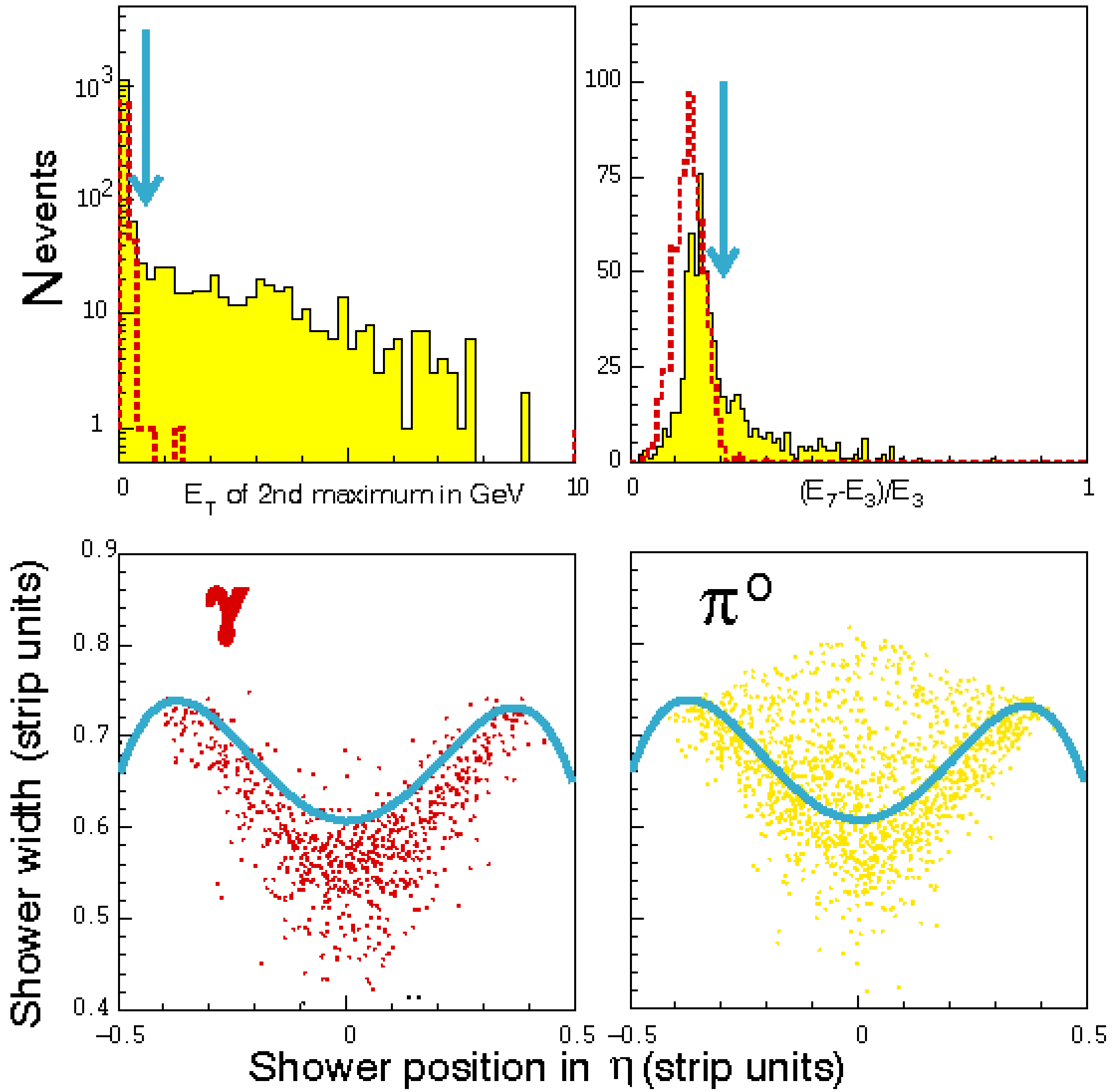
Ge: electron/gamma



CsI : g / p / a ...

Identification, isolation...

High energy :
Shower shape,
segmentation,
preshowers



ATLAS em p^0 rejection
(simulated)

Calorimetry at LHC: maximum constraints

- Collider => restricted space
- Large number of hits => small granularity 200000 channels
- 40 MHz repetition rate => fast signals ~ 50 ns peak
- Very demanding physics
    . large dynamic range : 1 GeV e tag (B physics) to 3 TeV (Z')
    . ~ 1% E-resolution (Higgs -> g g , Higgs -> 4 leptons)
    . ~ 10 mrad q resolution "
    . > 1000 jet rejection "

- High radiation flux
- One good feature only : 1 to 10 Z^0/second for calibration

Difficult to find a good compromise !

ATLAS and CMS e-m calorimeters

Each coming from a well-known line of techniques, but pushing it to the extreme in many aspects.

ATLAS: Liquid Argon [H1, D0, SLD, NA48…]

Ex : H1 , 45000 channels, peak time: 2.4 μs ; ATLAS , 184000 channels, 50 ns

CMS : Crystals […, L3, KTeV, BaBar…]

Ex L3 : 11000 crystals, peak time 1.1 μs, 1 % homogeneity

CMS: 83000 crystals, peak time 50 ns, 0.4 % homogeneity

=> Difficulties with series production processes.

Technologies far from the "market"

The special case of LEP

LEP : an e+ e- collider , without any narrow line for e-m calorimetry.

Energy resolution less crucial than granularity and *software*.

E-M and hadronic calorimetries intricated.

BIG use of kinematical fits

Low central detector occupancy => fine reconstruction of energy pattern

Charged particle removal, identification of neutral hadrons etc…

Interesting questions: the future e+e-

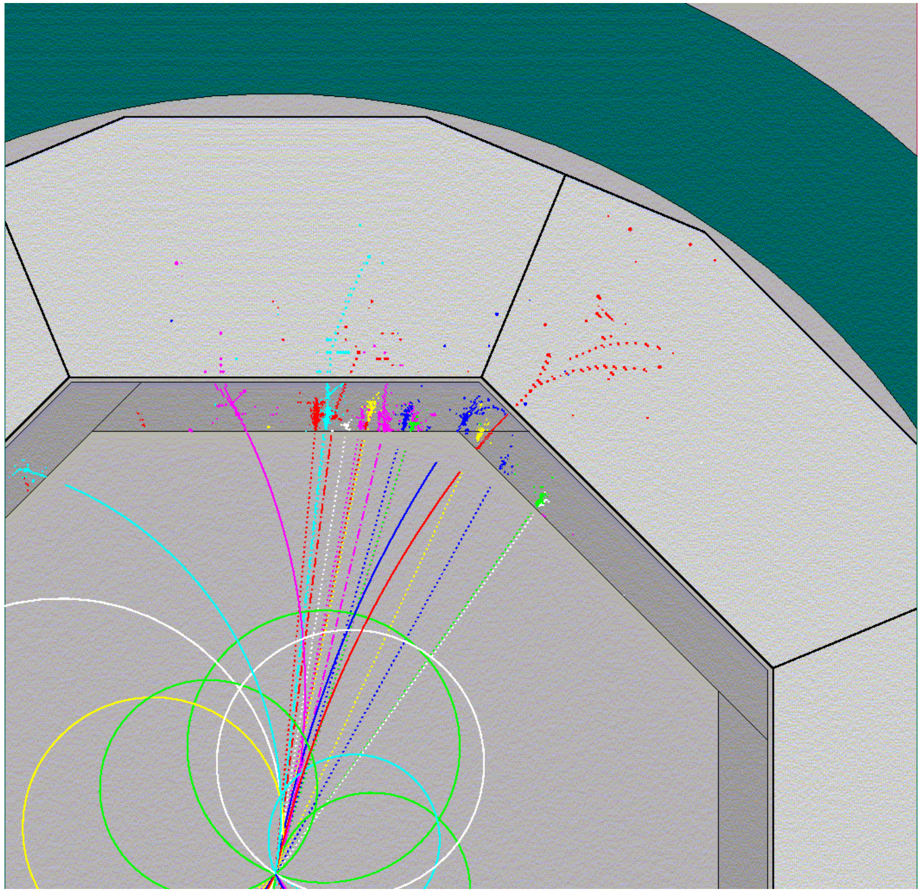
"Imaging calorimeter":

Tungsten absorbers, 1cm^2 Si pads

Continuous e-m/hadronic calorimetry

Main arguments, based on LEP experience:

ENERGY FLOW, particle ID.



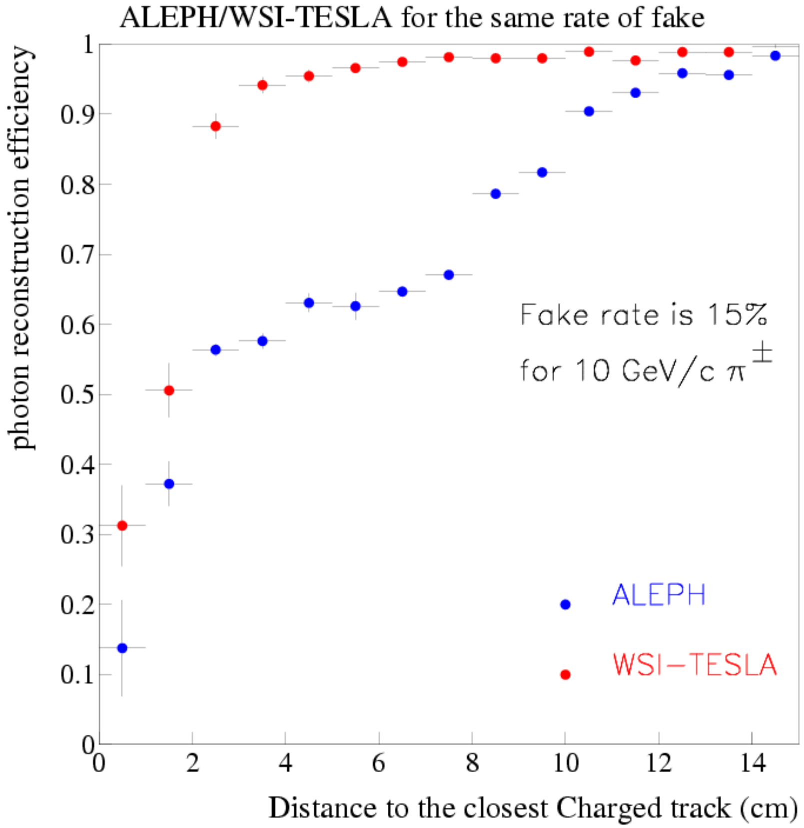
Calorimeter for the future e^+e^- collider ...

Real trend or fantasy?

- LEP: Role of hardware/software in ultimate E-flow resolution?

- 40 10^6 channels: dream or nightmare?

- Sensors/read-out: how close to the market?



g/charged separation in t physics

Conclusion

Trend 1: detectors go to compact, do-everything devices, i.e. calorimeters.

Trend 2: a certain tendency towards solid-state,
and inside this towards semiconductors

Trend 3: techniques (read-out, software) go across fields (probably not enough)

Not yet a trend, but should become one:
for large detectors, keep close to the market.
(research alone is now a small player)

A lot to learn by looking at neighbor fields: have a good conference!