CALORIMETRY

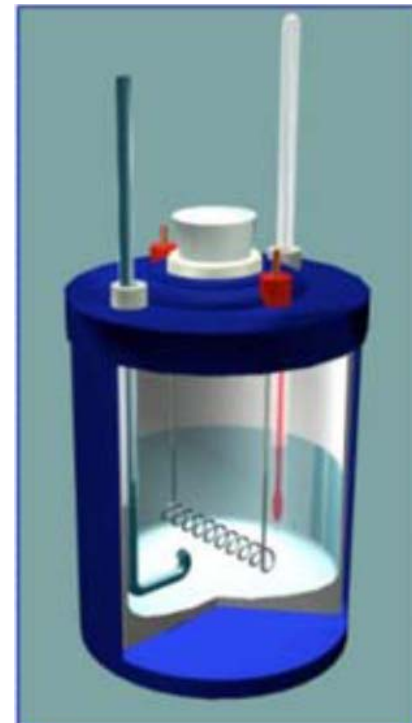## technology frontier & new trends of the field

Erika Garutti – DESY

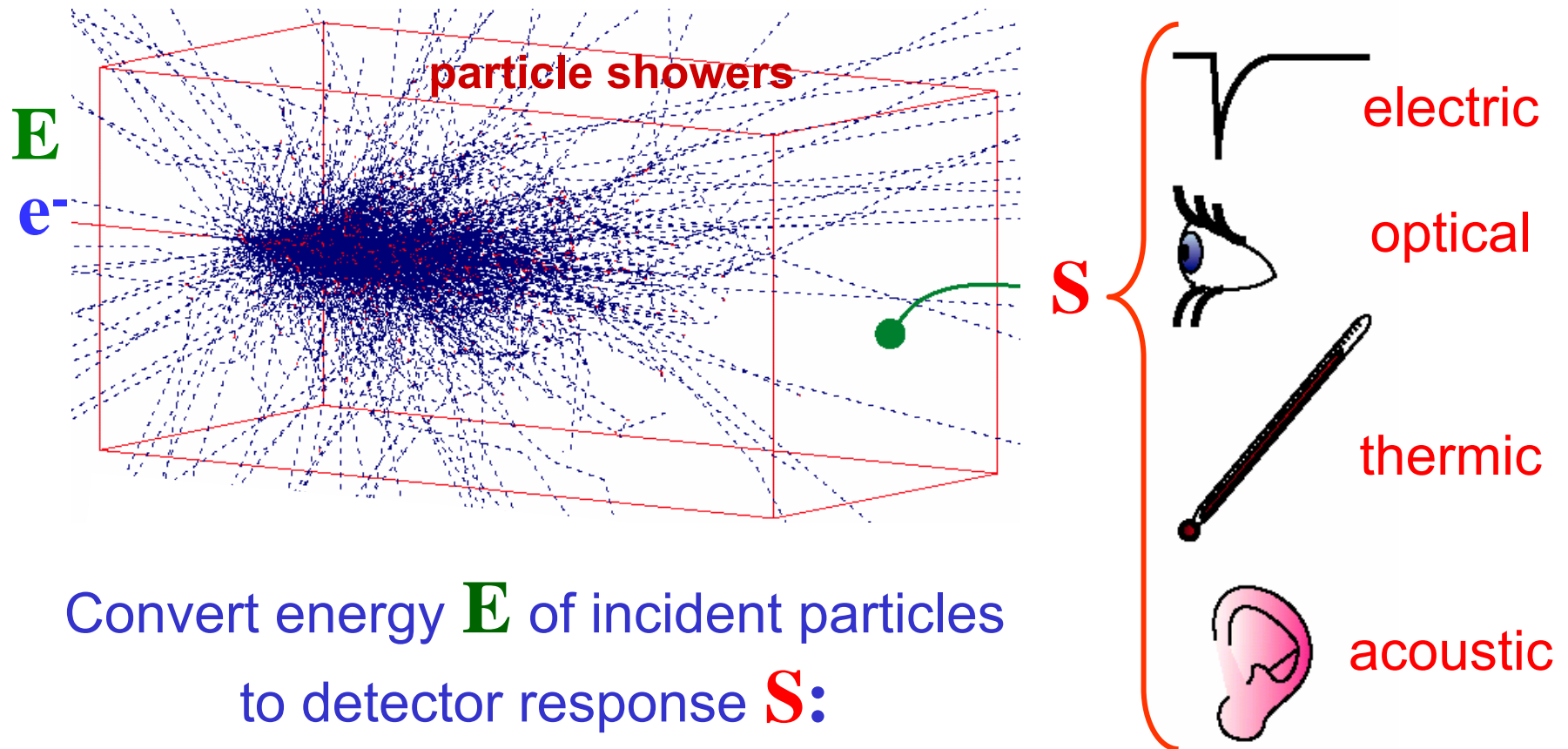Focus: calorimeters for HEP

Open questions:
- High granularity vs. compensation
- Analog vs. digital

CALO @ the technology frontier:
- extreme integration
- time resolution

Calorimeters: a simple concept

particle showers

E

e^-

S

electric

optical

thermic

acoustic

Convert energy E of incident particles to detector response S:

$$S \propto E$$

Emphasis on calo for future HEP exp.

|	
ZEHR	An ECAL prototype for the PEBS detector.
REPOND	Digital Hadron Calorimeter: a novel approach to calorimetry
MINARD	LHCb calorimeter calibration
JEANS	Test Beam Performance of the CALICE SiW Electromagnetic Calorimeter Physics Prototype
LAKTINEH	Semi-Digital Hadronic Calorimeter Using GRPCs for Future Linear Collider Experiments
SEIDEL	Particle Showers in a Highly Granular Hadron Calorimeter
KOTERA	Study of granular electromagnetic calorimeter with PPDs and the scintillator strips for ILC
CALVO GOMEZ	New Results from the DREAM project
KOLETSOU	The ATLAS Liquid Argon Calorimeter at the LHC

5 contributions on ILC calorimeters
1 contribution on dual readout (ILC/CLIC)

Calorimeter R&D for HEP detectors

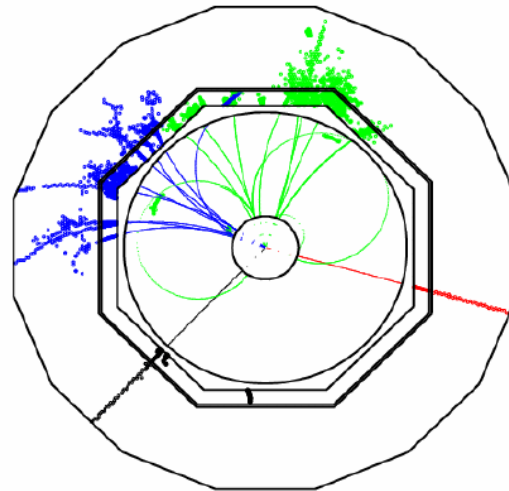The largest scale HEP detectors at (s)LHC and the future LC

The LHC $pp \rightarrow H + X$
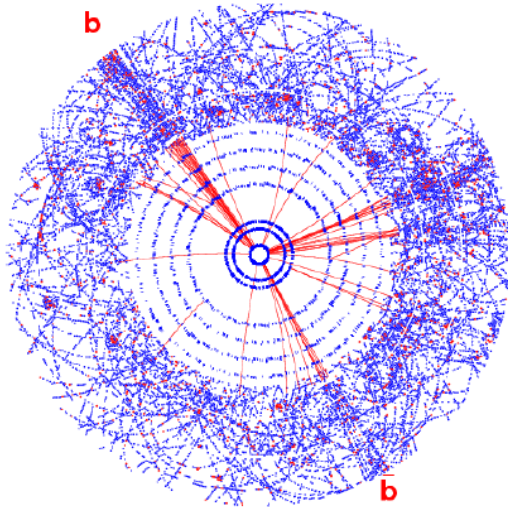
The ILC $e^+e^- \rightarrow HZ$

★ **At electron-positron the final state corresponds to the underlying physics interaction, e.g. above see** $H \rightarrow b\bar{b}$ **and** $Z \rightarrow \mu^+\mu^-$ **and nothing else…**

High precision LC physics demands a high precision detector:
- high precision vertex (flavor tagging) and tracking (Higgs from di-lepton recoil mass)
- precision calorimetry (heavy bosons reconstruction from di-jet decay)
➜ significant improvements in the calo. system, in particular in the HCAL

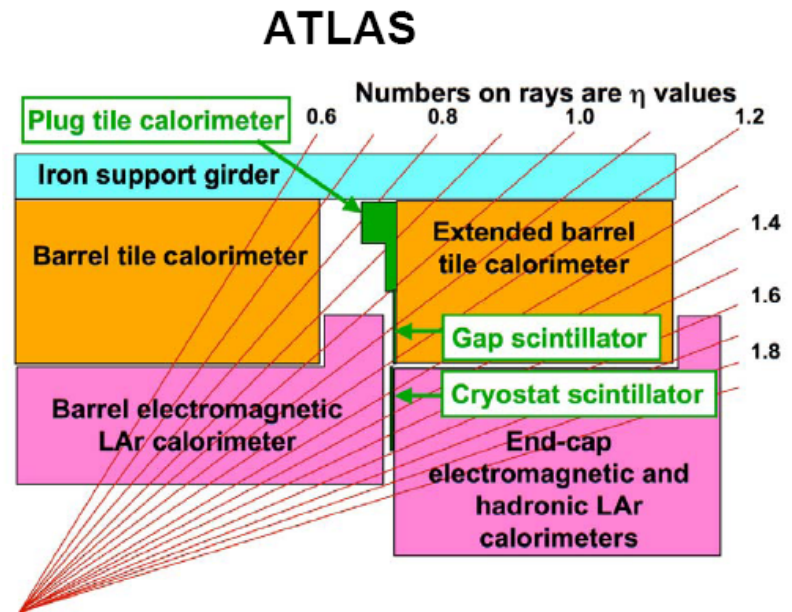# Jet energy resolution at LHC

CMS
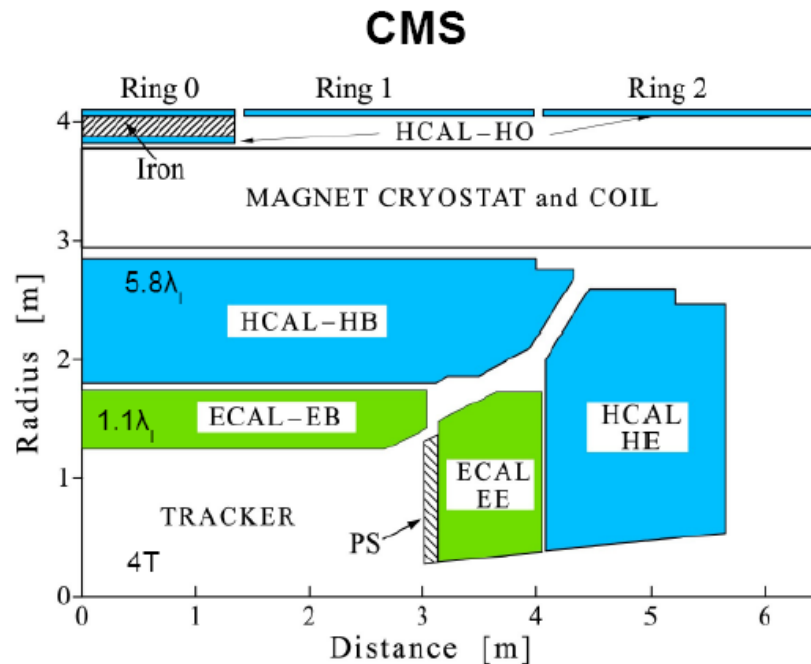
5 cm brass / 3.7 cm scint.
Embedded fibres, HPD readout

Expected jet resolution:

$$\frac{\sigma}{E} = \frac{125\%}{\sqrt{E}} \oplus \frac{5.6 \text{ GeV}}{E} \oplus 3.3\%$$

ATLAS

14 mm iron / 3 mm scint.
sci. fibres, read out by phototubes

Jet resolution with weighting:

$$\frac{\sigma}{E} = \frac{60\%}{\sqrt{E}} \oplus 3\%$$

Stochastic term for hadrons was ~93% and 42% respectively

Energy resolution: the next generation

how to improve jet energy resolution to match the requirement of the new physics expected in the next 30-50 years:

➔ Attack fluctuations

Hadronic calorimeter largest fluctuations (if not compensating)

Two approaches:
- minimize the influence of the calorimeter
  ➔ measure jets using the combination of all detectors
     Particle Flow

- measure the shower hadronic shower components in each event & weight
 ➔ directly access the source of fluctuations
     Dual (Triple) Readout
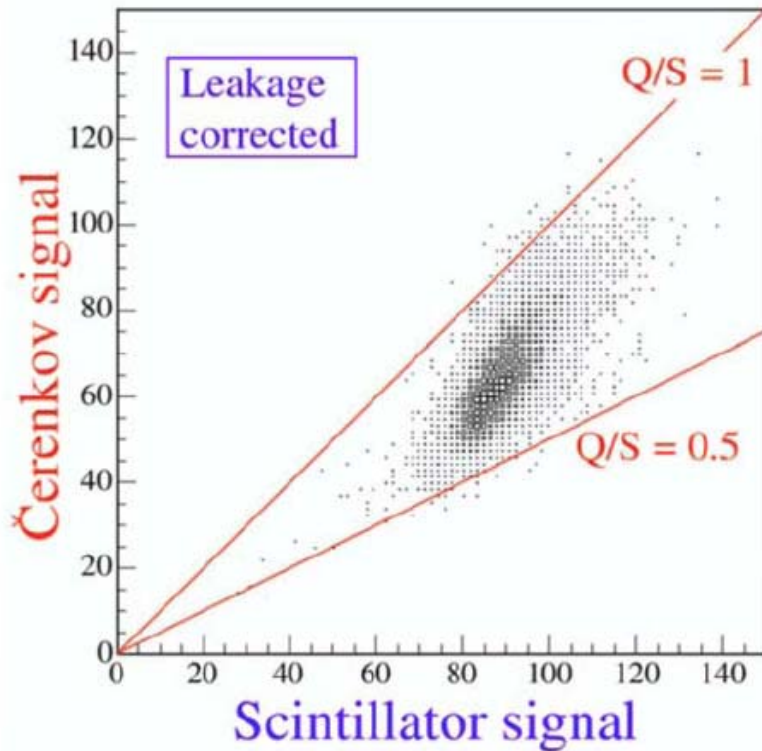
Dual Readout Calorimetry
the DREAM Collaboration

- Measure f_{EM} cell-by-cell by comparing Cherenkov and dE/dx signals
- Densely packed SPACAL calorimeter with interleaved Quartz (Cherenkov) and Scintillating Fibers
- Production of Cerenkov light only by em particles (f_{EM})
    from CMS-HF (e/h=5) ~80% of non-em energy deposited by non-relativistic particles
- 2 m long rods (10 λ_{int}) with no longitudinal segmentation

What is the dream? Measure jets as accurately as electrons, i.e.
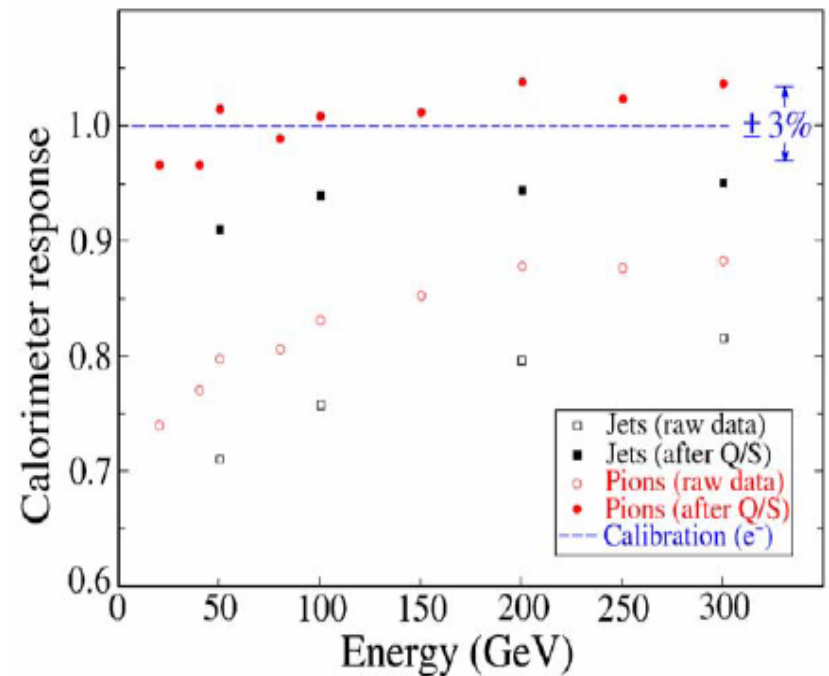$$\sigma_E/E \sim 15\%/\sqrt{E}$$
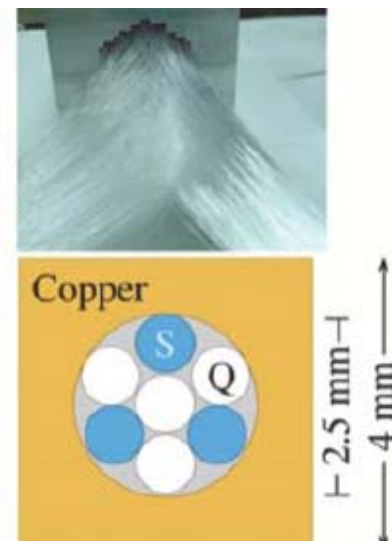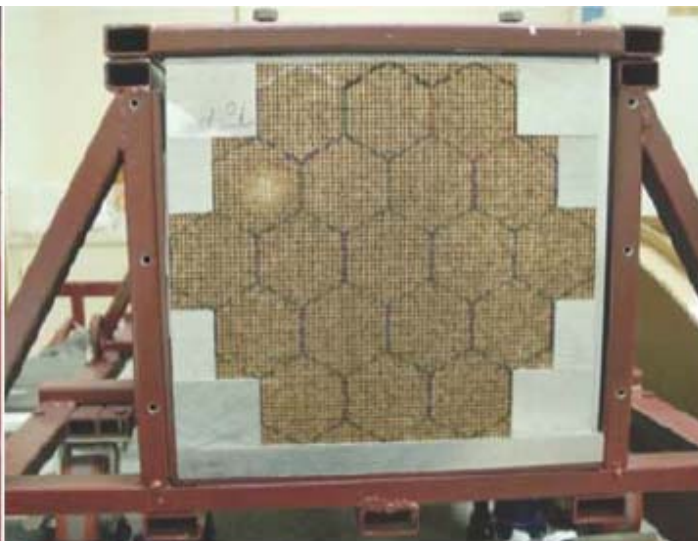
Determination of f_{EM}

➔ Extract f_{EM} from the Q/S ratio

$$\frac{Q}{S} = \frac{R_Q}{R_S} = \frac{f_{em} + 0.20(1 - f_{em})}{f_{em} + 0.77(1 - f_{em})}$$

Q/S<1 ➔ ~25% of the scintillator signal from pion showers is caused by non-relativistic particles, typically protons from spallation or elastic neutron scattering
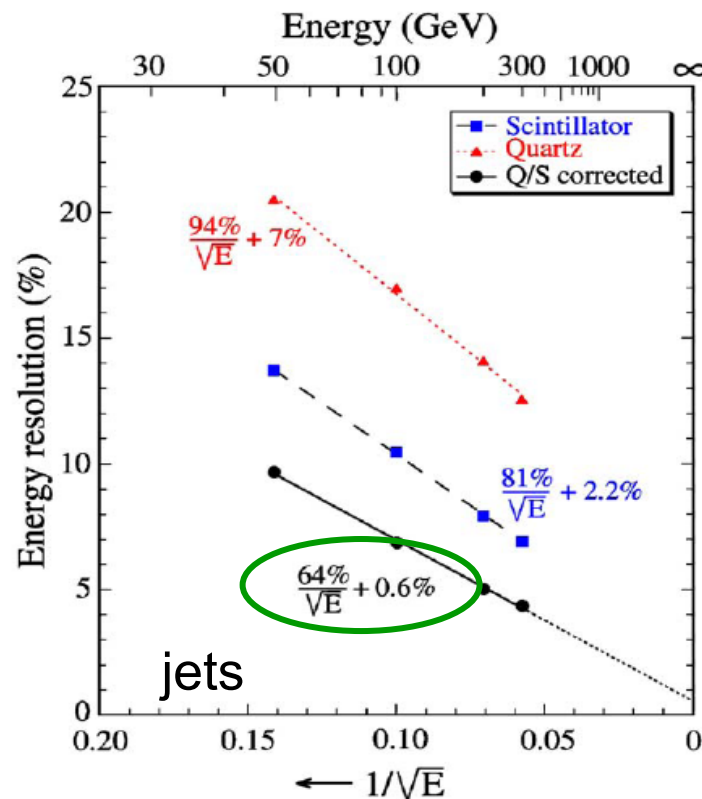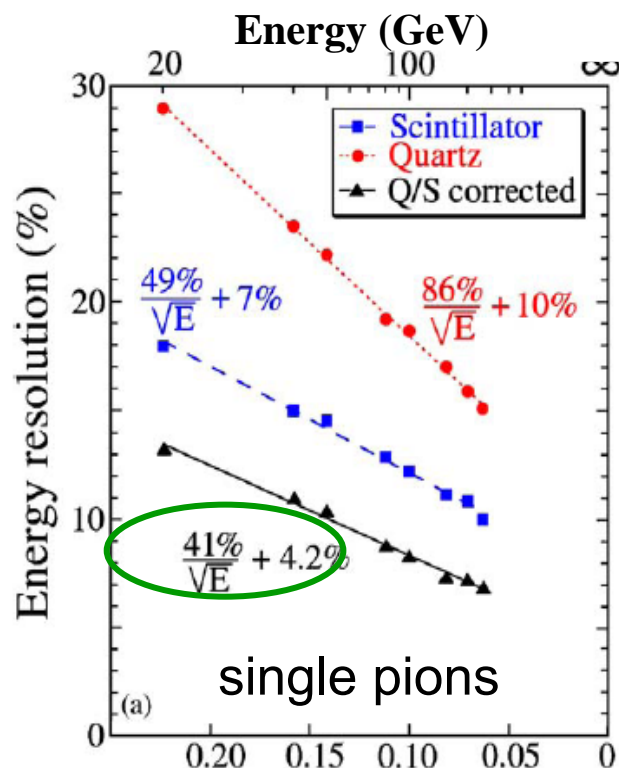
Recovered linearity of response to pions and "jets"

Energy resolution

single pions — $\frac{49\%}{\sqrt{E}} + 7\%$, $\frac{86\%}{\sqrt{E}} + 10\%$, $\frac{41\%}{\sqrt{E}} + 4.2\%$ (Scintillator, Quartz, Q/S corrected)

jets — $\frac{94\%}{\sqrt{E}} + 7\%$, $\frac{81\%}{\sqrt{E}} + 2.2\%$, $\frac{64\%}{\sqrt{E}} + 0.6\%$ (Scintillator, Quartz, Q/S corrected)

Significant improvement in energy resolution especially for jets

Next challenges:
1) re-gain partial longitudinal segmentation (ECAL/HCAL) ➜ Dual readout of BGO crystals exploiting the fast Cherenkov response
2) add Triple readout ➜ measure the neutron component with hydrogenous materials

Particle Flow

• Particle flow is a concept to improve the jet energy resolution of a HEP detector based on:

> proper detector design (high granular calorimeter!!!)
>
> + sophisticated reconstruction software

• PFlow techniques have been shown to improve jet E resolution in existing detectors, but the full benefit can only be seen on the future generation of PFlow designed detectors
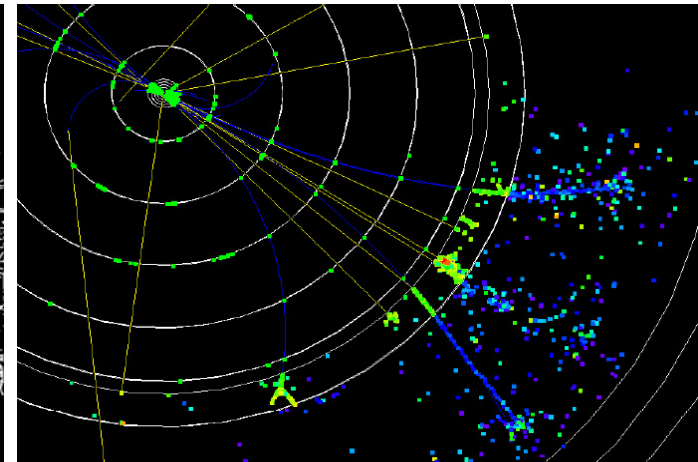
Requires the design of
- a highly granular calorimeter, $O(1cm^2)$ cells
- dedicated electronics, $O(20M$ channels)
- high level of integration

Doesn't it remind you of much more common pictures?
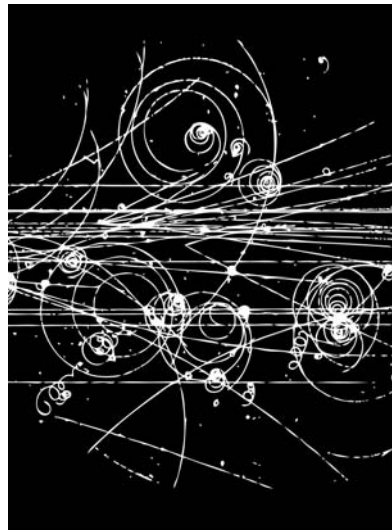
Full event reconstruction with a particle flow algorithm

Particle Flow paradigm

→ reconstruct every particle in the event
- up to ~100 GeV Tracker is superior to calorimeter →
- use tracker to reconstruct $e^{\pm}, \mu^{\pm}, h^{\pm}$ (<65%> of E_{jet})
- use ECAL for γ reconstruction (<25%>)
- (ECAL+) HCAL for h^0 reconstruction (<10%>)

→ HCAL E resolution still dominates E_{jet} resolution
→ But much improved resolution (only 10% of E_{jet} in HCAL)

$$E_{JET} = E_{ECAL} + E_{HCAL}$$

$$E_{JET} = E_{TRACK} + E_{\gamma} + E_n$$
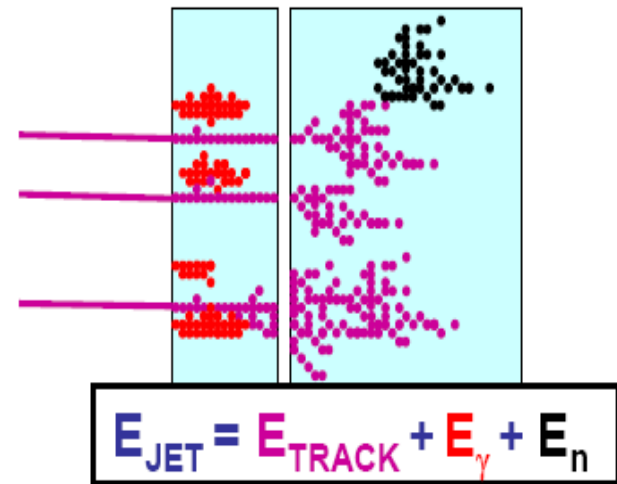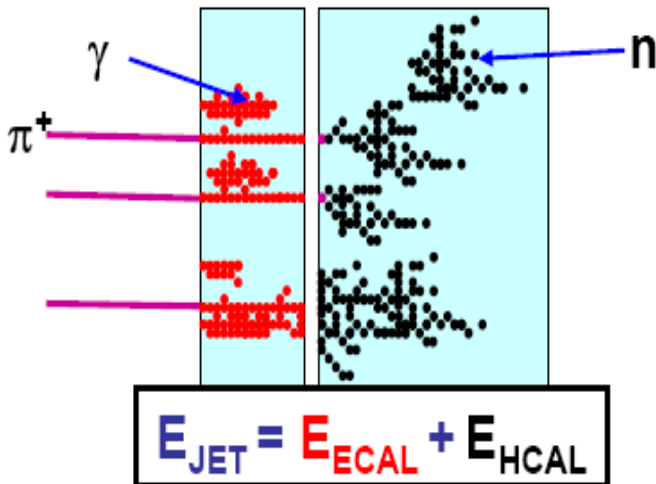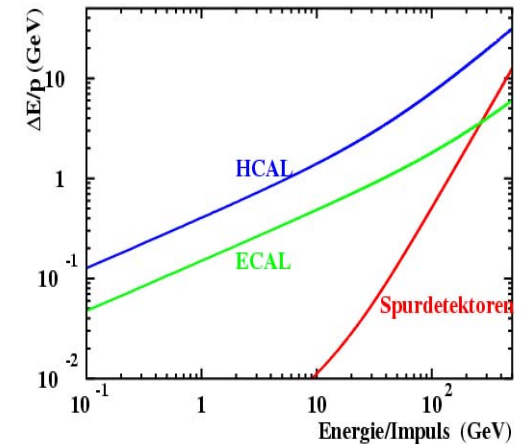
PFLOW calorimetry = Highly granular detectors (CALICE) + Sophisticated reconstruction software
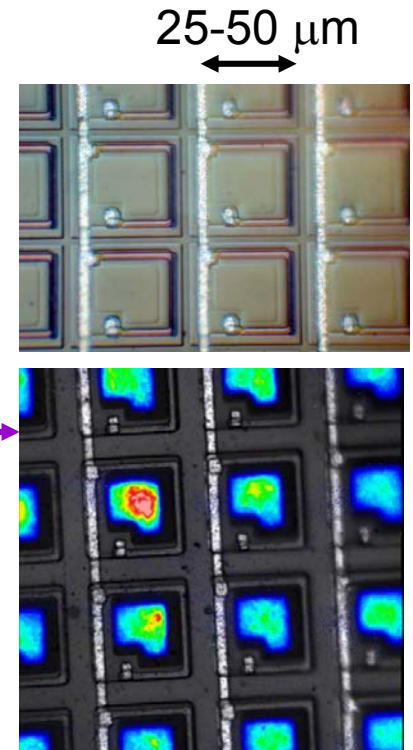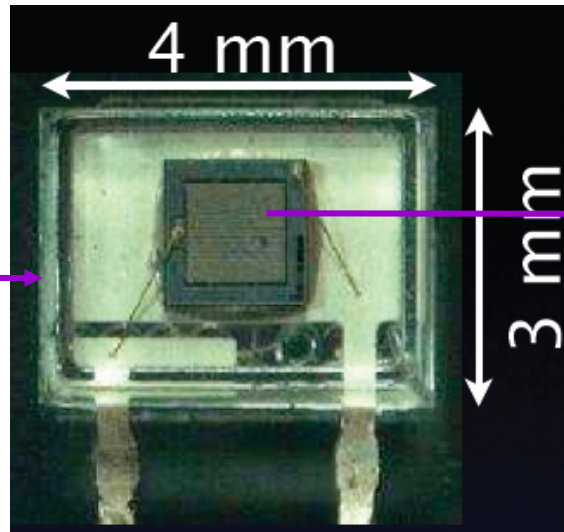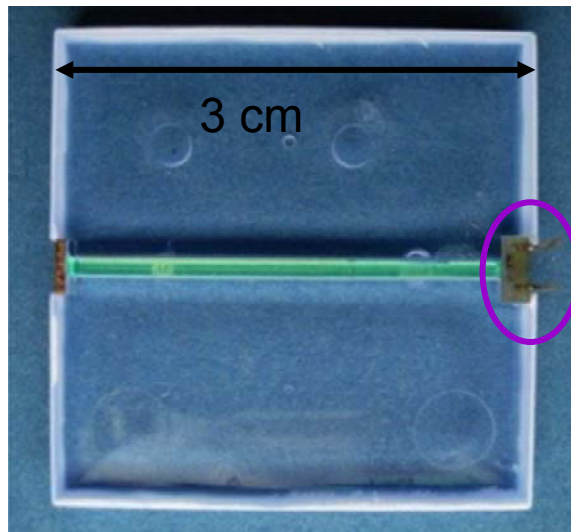
The technology tree
Calorimeter ZOO
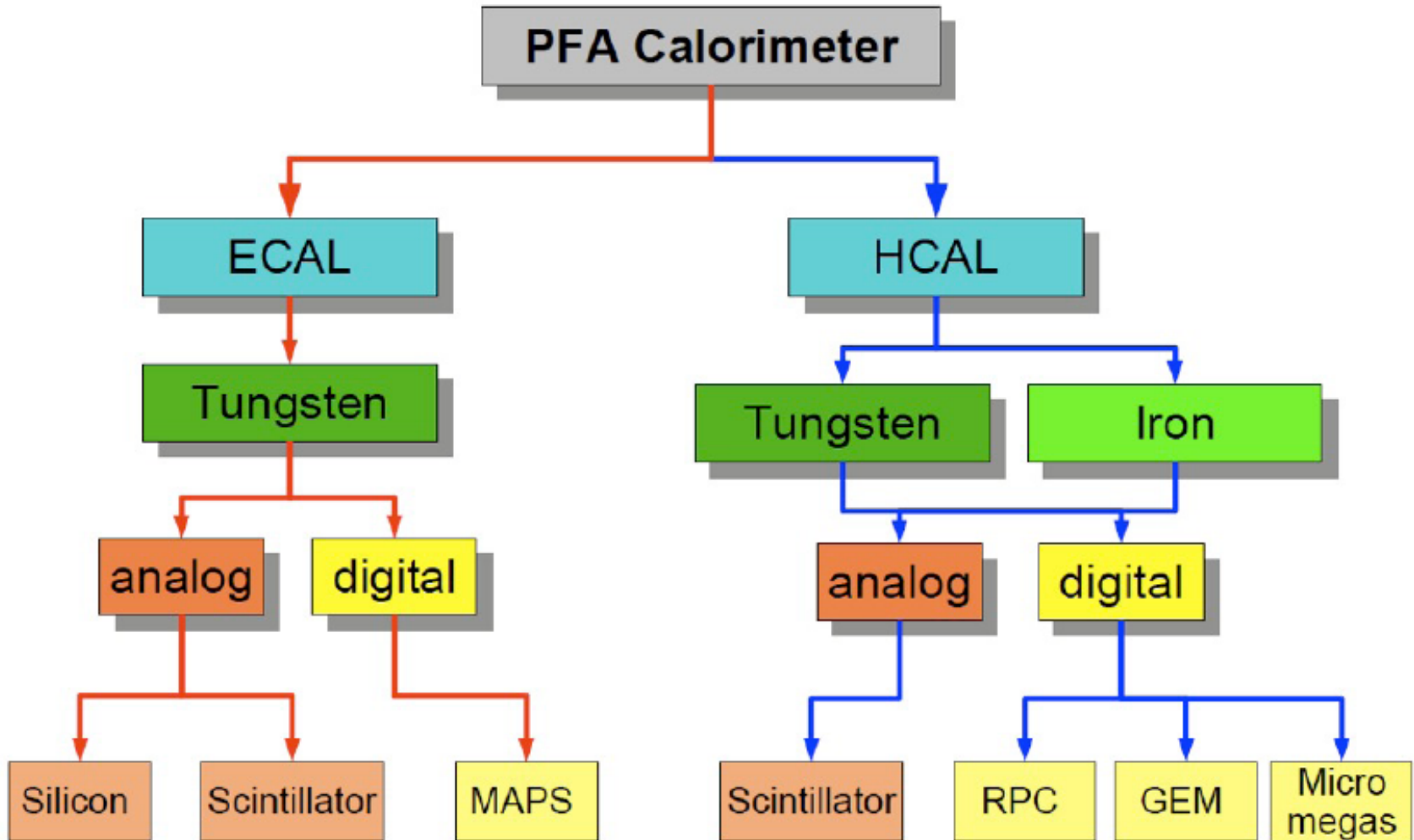
High granularity with plastic scintillator

Basic technique for the active media:
- Single scintillator tile or strips, 3-5mm thickness
- Light collection via a WLS fiber
- Coupled to a Silicon PhotoMultiplier (SiPM) detector:
  pixel device operated in Geiger mode

25-50 μm

3 cm

4 mm

3 mm

- Blue/UV sensitive SiPM allow direct coupling to scintillator
- dynamic range limited by SiPM saturation

A short parenthesis on SiPM

Large number of dedicated contributions in this conference

CIBINETTO	Results from Silicon Photo-Multiplier neutron irradiation test
AHMED	Study of timing performance of Silicon Photomultiplier and application for a Cherenkov detector
VALLAZZA	Performance Of Shashlik Calorimeters Read Out By Silicon Photomultipliers
DOLENEC	Tests of a Silicon Photomultiplier Module for Detection of Cherenkov Photons
COLLAZUOL	Studies of Silicon Photo-Multipliers at cryogenic temperatures
VERHEYDEN	Performance Study of Silicon Photomultipliers as Photon Detector for PET
NINKOVIC	The First measurements on SiPMs with Bulk Integrated Quench Resistors
ANFIMOV	Novel Micropixel Avalanche Photodiodes (MAPD) with super high pixel density.
ROY	Study of the spectral sensitivity of G-APDs in the wavelength range from 250 to 800 nm

… requires a brief status of SiPM

SiPM (or G-APD) shopping plaza

Increasing number of applications and producers

<u>My personal</u> list of interesting devices:

The most known: MPPC   http://www.hamamatsu.com/
Reliable/ mass produced/ blue sensitive/ good performance parameters

MEPHI/ PULSAR

4 mm
3 mm

Larger dynamic range / radiation harder: MAPD http://www.zecotek.com/
Lower gain / O(15000pix/mm^2)

Reliable mass production: SenseL SiPM   http://sensl.com/products/
Not very aggressive parameters but stable on large scale

Longer recovery time than MPPC:CPTA   http://www.cpta-apd.ru/
Smaller after-pulse / smaller crosstalk

UV sensitive (prototype): KETEK SiPM   http://www.ketek.net/   Talk by J. Ninkovic
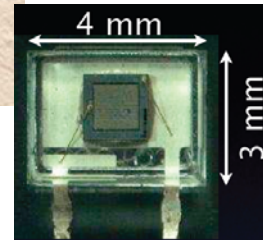
New interesting development: SiMPL (MPI Munich)
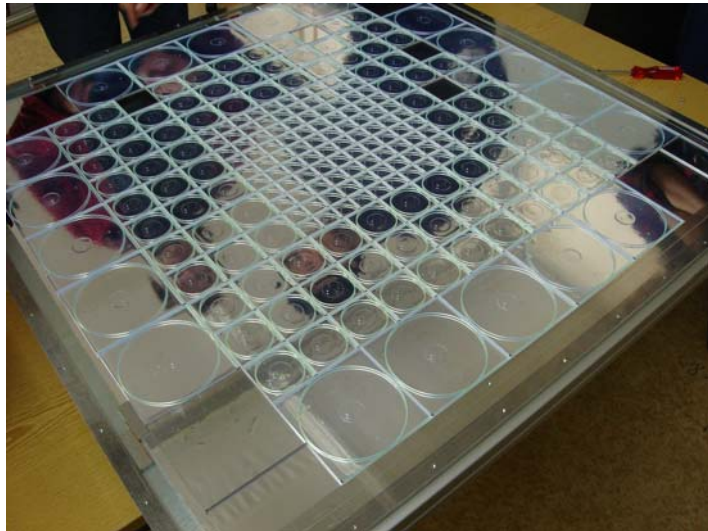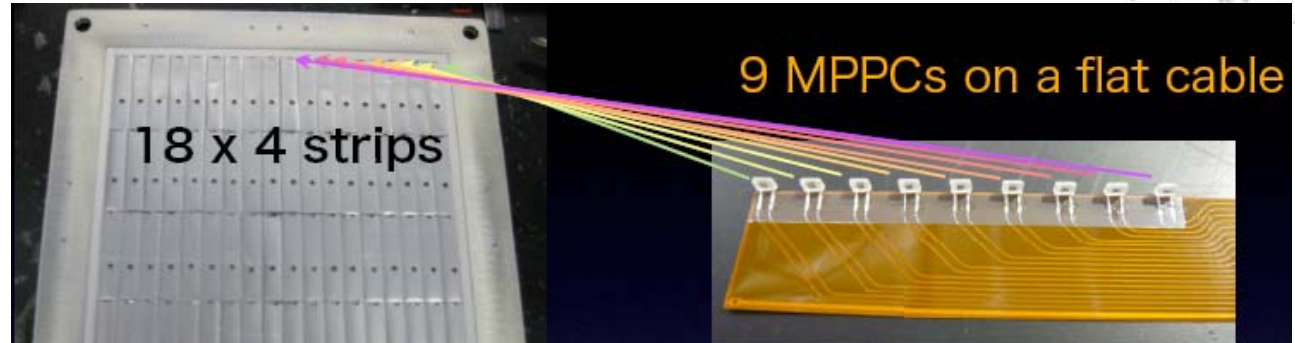no poly-silicon resistor / higher geometrical fill factor
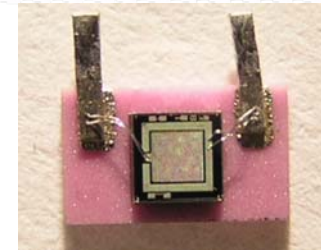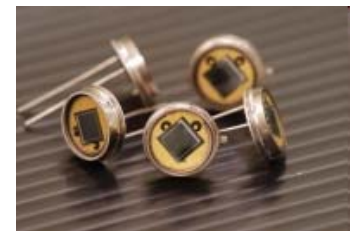
Tested prototypes

The CALICE collaboration

Scint/W ECAL
$0.3 \times 1 \times 4.5 cm^3$ strips
MPPC (Hamamatzu)
~2200 channels
26 layers / 18.5 X_0

18 x 4 strips

9 MPPCs on a flat cable

Scint/Fe HCAL
$0.5 \times 3 \times 3 cm^3$ tiles
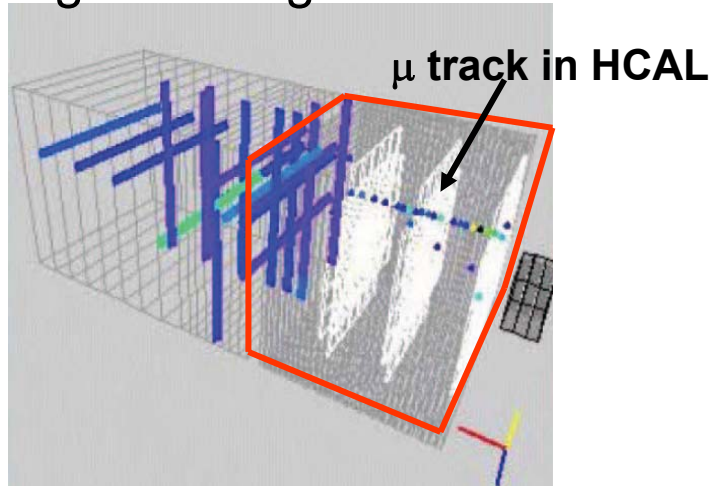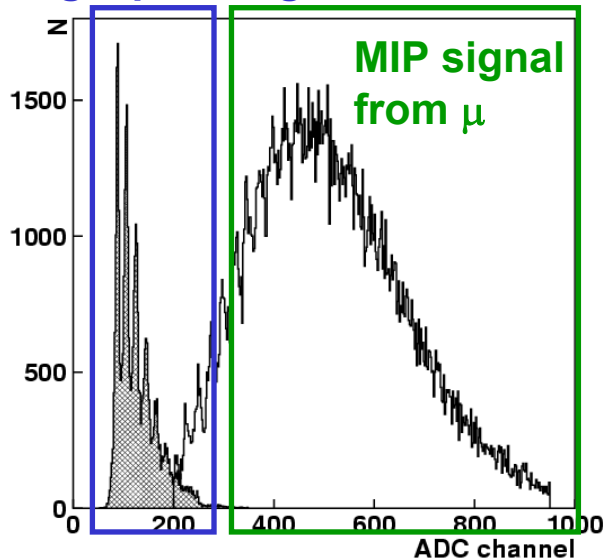SiPM (MEPHI/PULSAR)
~8000 channels
38 layers / 4.5 λ_{int}
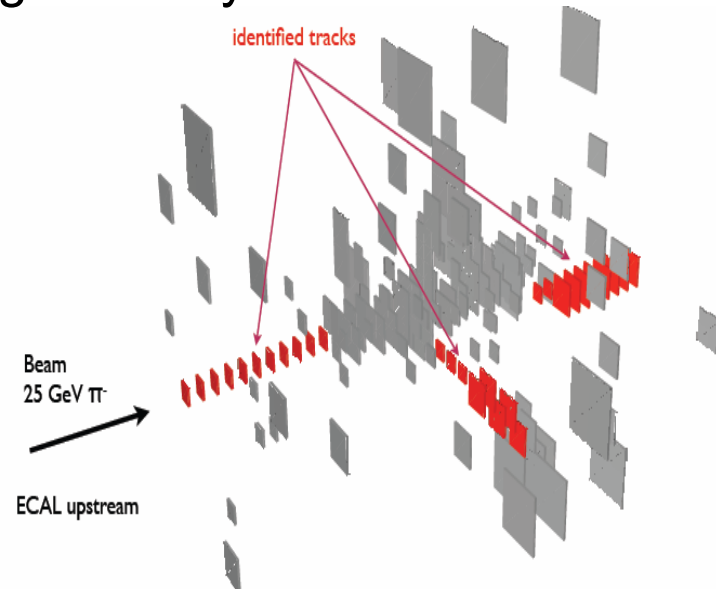
Cell response equalization with MIP

Using muon signal

μ **track in HCAL**

Single pixel signal from SiPM

MIP signal from μ

Using pion shower
select MIP stubs using the high
granularity of the HCAL

identified tracks

Beam
25 GeV π⁻

ECAL upstream

Luminosity requirement for in-situ calibration with
MIP stabs from jets (ILC detector)

	Luminosity at 91 GeV	Luminosity at 500 GeV
layer-module to 3% to layer 20	1 pb^{-1}	1.8 fb^{-1}
layer-module to 3% to layer 48	10 pb^{-1}	20 fb^{-1}
HBU to 3% to layer 20	20 pb^{-1}	36 fb^{-1}

more statistics obtained from $Z_0 \rightarrow \mu\mu$ events

The power of high granularity

Capability of π_0 reconstruction in Scint/W-ECAL
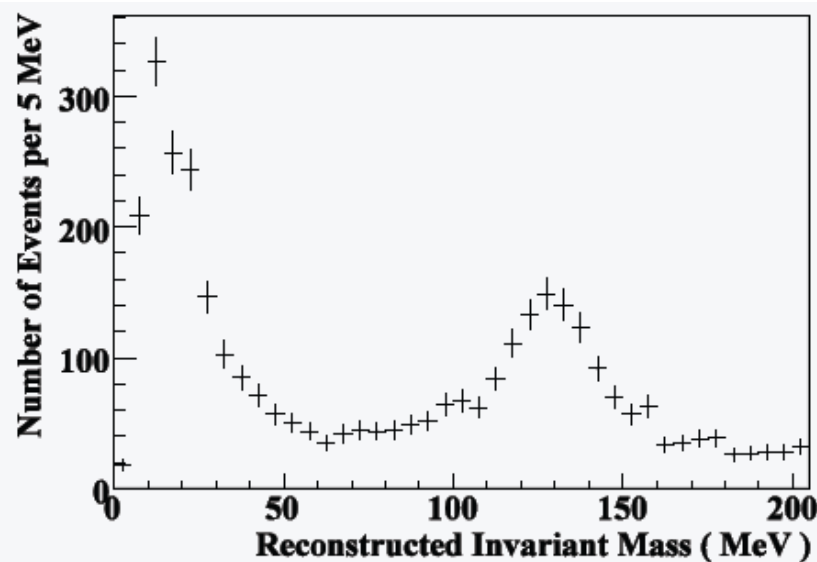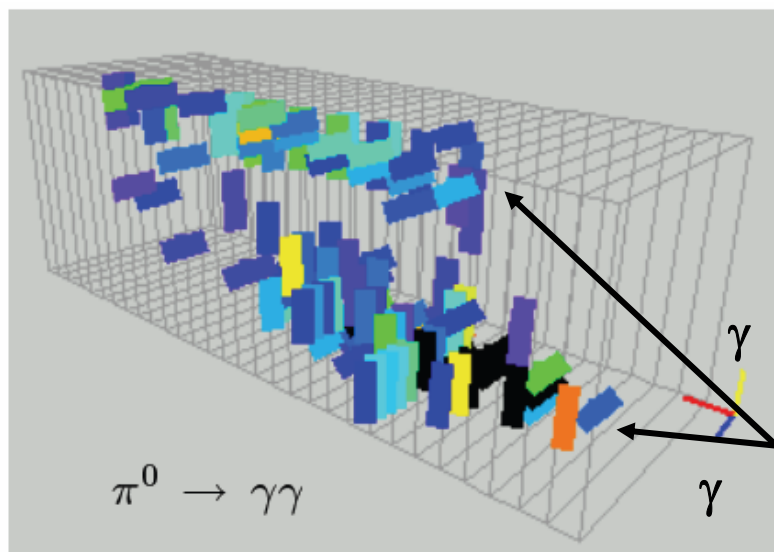
Production target 1.8 m upstream of the detector

The power of high granularity

REAL DATA!

Shower from a 40 GeV $\pi+$

ECAL Hits: 302 Energy: 1446.42 mips
HCAL Hits: 231 Energy: 803.441 mips
TCMT Hits: 22 Energy: 60.008 mips

mips

Scint/Fe HCAL

40GeV/c pion with CALICE online analysis software
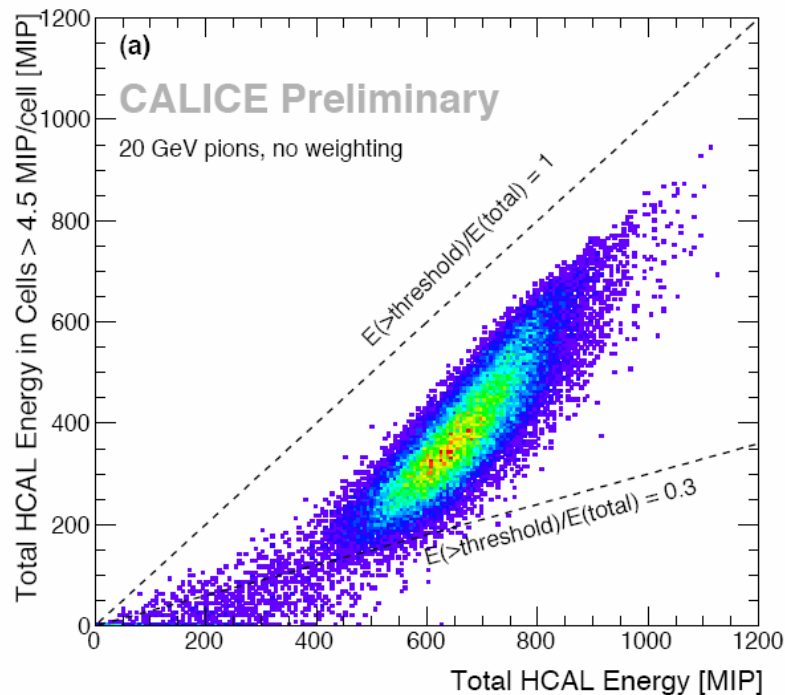
Imaging calorimetry

Late shower in HCAL

Clear structure visible in hadronic shower
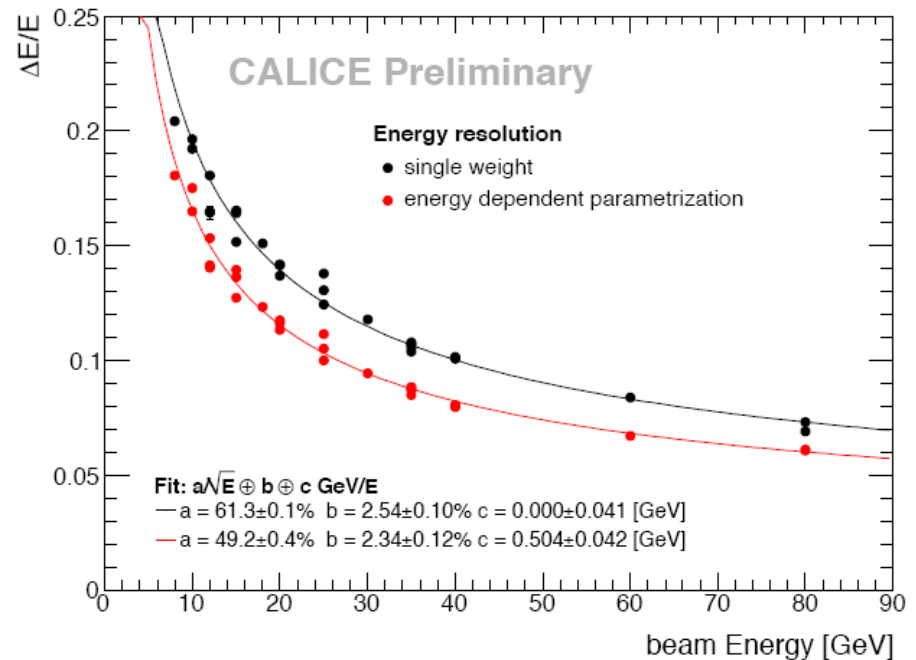
Clear determination of the first interaction

Energy density weighting

High energy density in small
calo. cells proportional to f_{EM}

E resolution improvement:
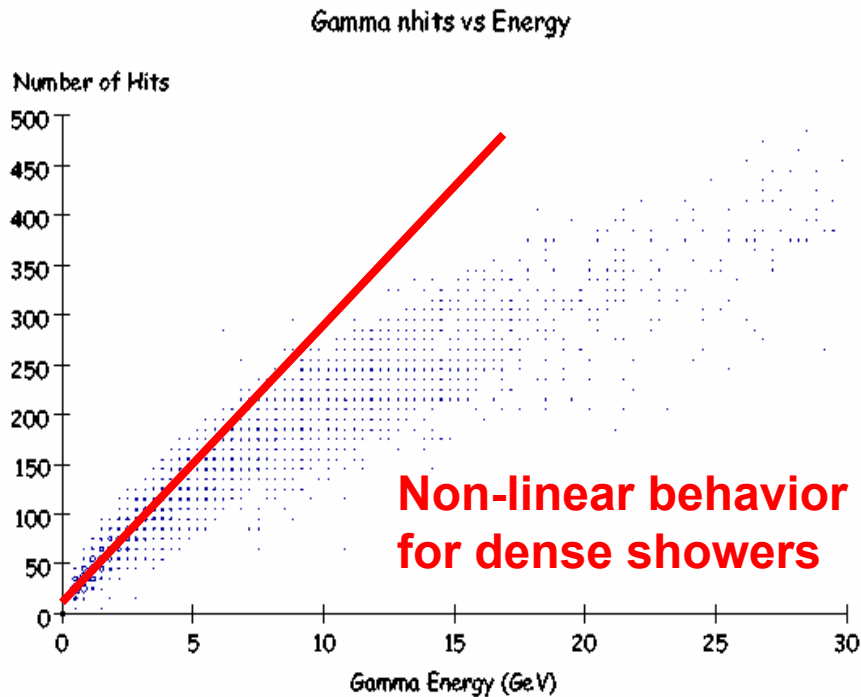

Use this correlation to apply
weighting corrections event-by-event

stochastic term 60% ⟶ 50% / √E using
energy density weighting technique

Analog .vs. Digital

photon analysis

$$E_\gamma \neq \sum N_i$$

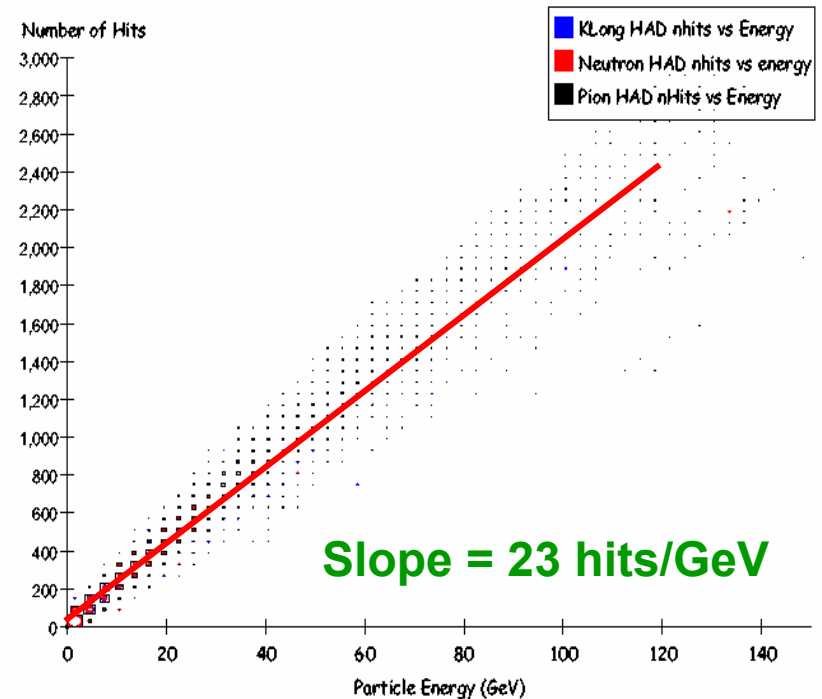**ECAL: Analog readout required**

Gamma nhits vs Energy

Number of Hits

Non-linear behavior for dense showers

hadron analysis

$$E_h \propto \sum N_i$$

HCAL: either Analog or Digital readout

Number of Hits

■ KLong HAD nhits vs Energy
■ Neutron HAD nhits vs energy
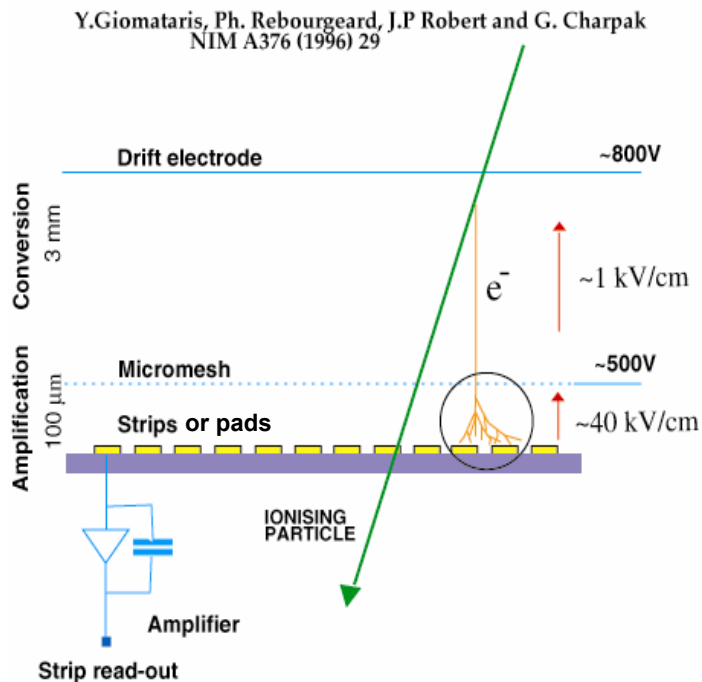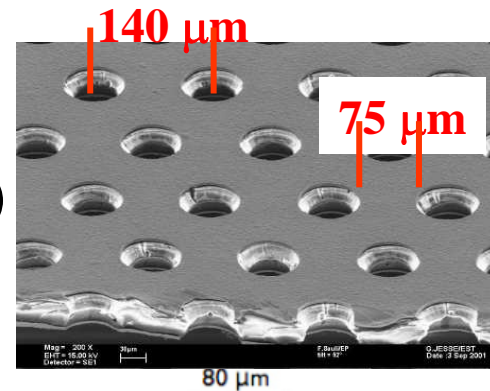■ Pion HAD nHits vs Energy

Slope = 23 hits/GeV

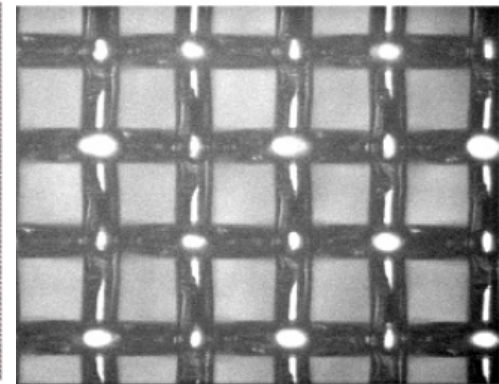Calorimeter cell size 1x1cm^2

The Digital HCAL

Basic technique for the active media:

- Ionization-gas chambers with charge amplification (RPC, GEM, MicroMegas)
- digital readout on silicon pads 1x1cm^2
- integrated electronics inside active layer
- high level of data concentration (~0.5 M channels / m^3)

Gas Electron Multiplier foil

140 μm

75 μm

80 µm

Y.Giomataris, Ph. Rebourgeard, J.P Robert and G. Charpak
NIM A376 (1996) 29

Drift electrode — ~800V

Conversion 3 mm

~1 kV/cm

e$^-$

Micromesh — ~500V

Amplification 100 µm

Strips or pads — ~40 kV/cm

IONISING PARTICLE

Amplifier

Strip read-out

2 mm

MICROMEGAS in a bulk
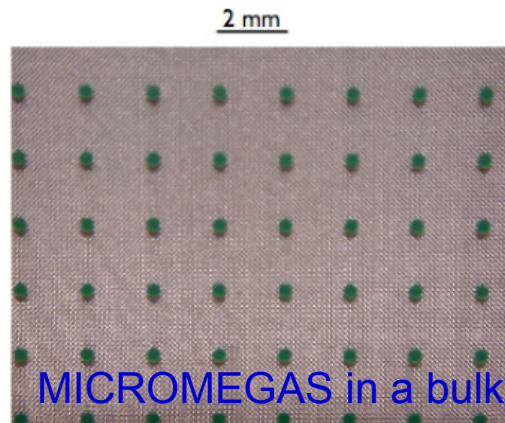
Pillars: 400u Ø, 100u height
Ampl. gap 25-150µm $\rightarrow$ narrow avalanches
excellent spatial and time resolution

The Digital HCAL

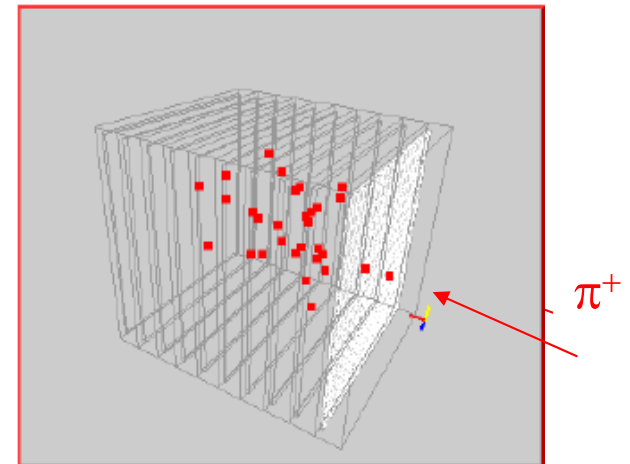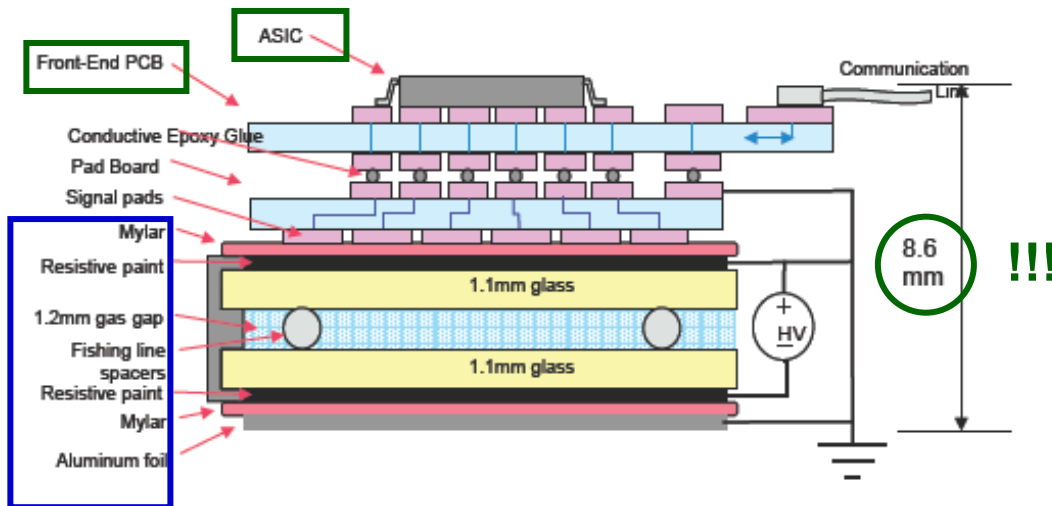## The CALICE collaboration

mechanic challenge !
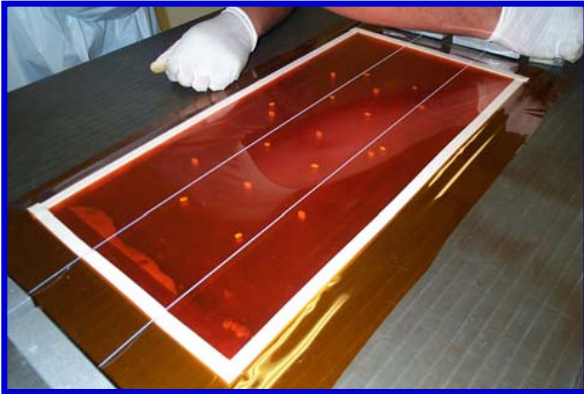
Active layers of glass RPCs
1 cm^2 pads
one bit readout per channel

Proof of principle measurement at
FNAL test beam:

small prototype
20 x 20 cm^2 active area

Front-End PCB
ASIC
Communication Link

Conductive Epoxy Glue
Pad Board
Signal pads
Mylar
Resistive paint

1.2mm gas gap
Fishing line
spacers
Resistive paint
Mylar
Aluminum foil

1.1mm glass

1.1mm glass
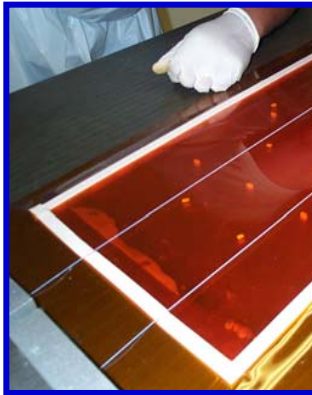
8.6 mm **!!!**

HV

π^+

B.Bilki et al., JINST 4:P04006, 2009

shower in a DHCAL prototype
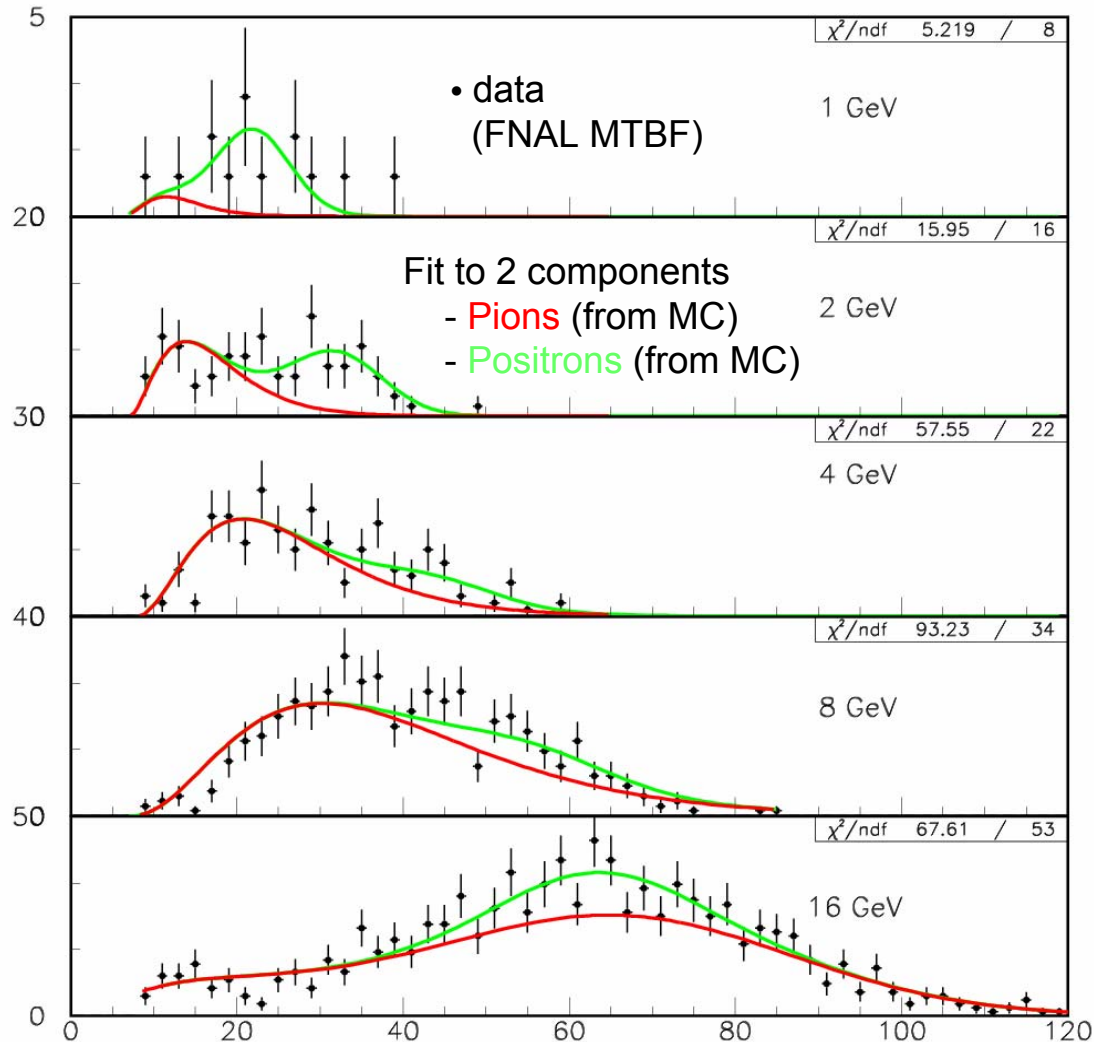
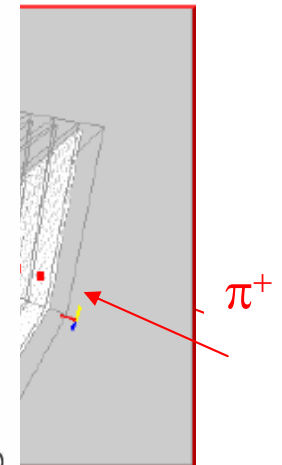# The Digital HCAL

The CALICE collaboration

mechanic chall...   ...ss RPCs

...channel

Fit to 2 components
- Pions (from MC)   ...easurement at
- Positrons (from MC)

- data (FNAL MTBF)

...area

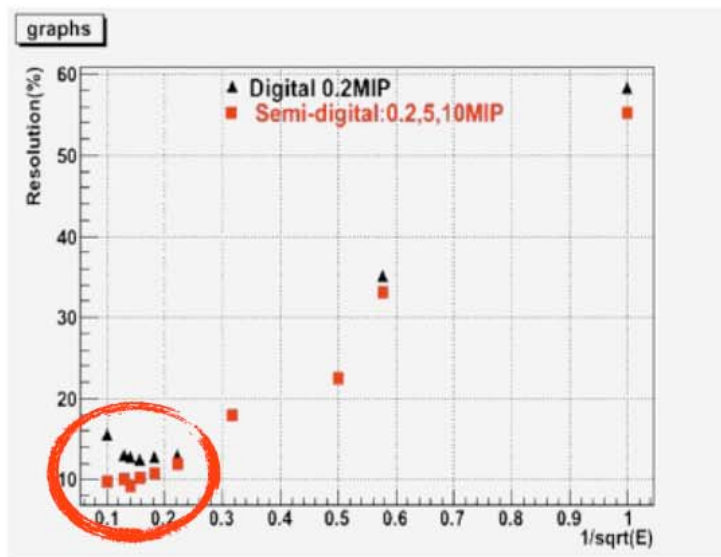π^+
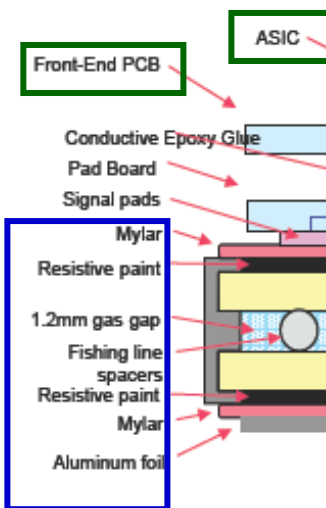
B.Bilki et al., JINST 4:P04006, 2009   ...L prototype
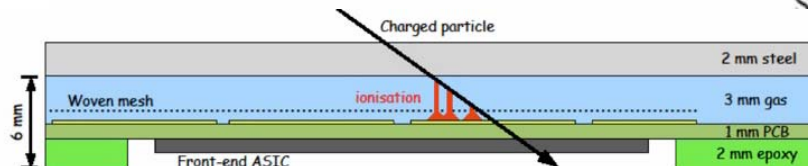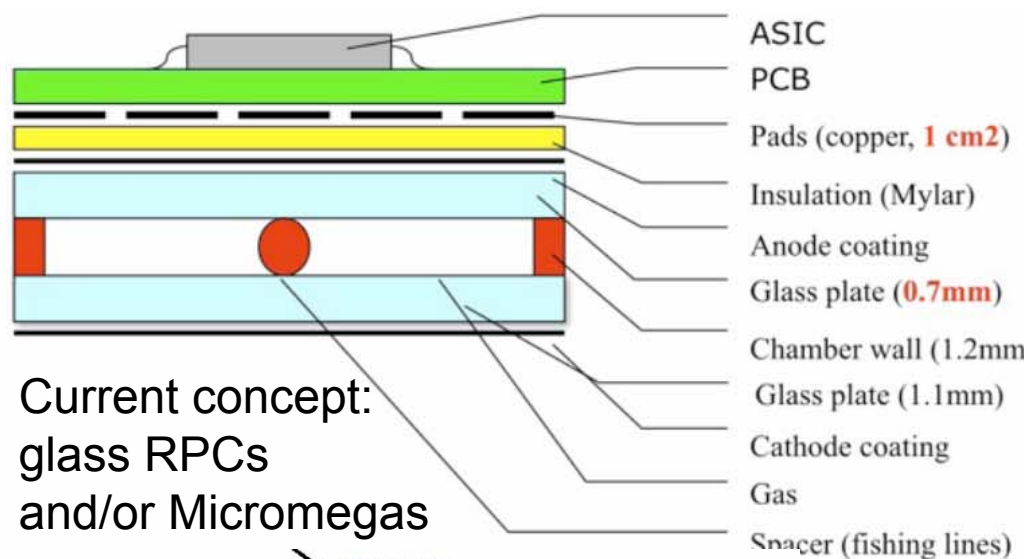
Semi-digital HCAL

- The motivation: Avoid the limited dynamic range of a digital HCAL, keep the simplicity of a gas detector readout
  - 2 bit per cells: 3 thresholds

Concept so far unproven, depends on detailed response characteristics of the detectors: Test required!

Simulations show the potential for significant improvement of resolution at high energies

Current concept: glass RPCs and/or Micromegas

ASIC
PCB
Pads (copper, 1 cm2)
Insulation (Mylar)
Anode coating
Glass plate (0.7mm)
Chamber wall (1.2mm
Glass plate (1.1mm)
Cathode coating
Gas
Spacer (fishing lines)

Analog .vs. Digital

photon analysis

$$E_\gamma \neq \sum N_i$$

hadron analysis

$$E_h \propto \sum N_i$$

ECAL: Analog readout required

HCAL: either Analog or Digital readout

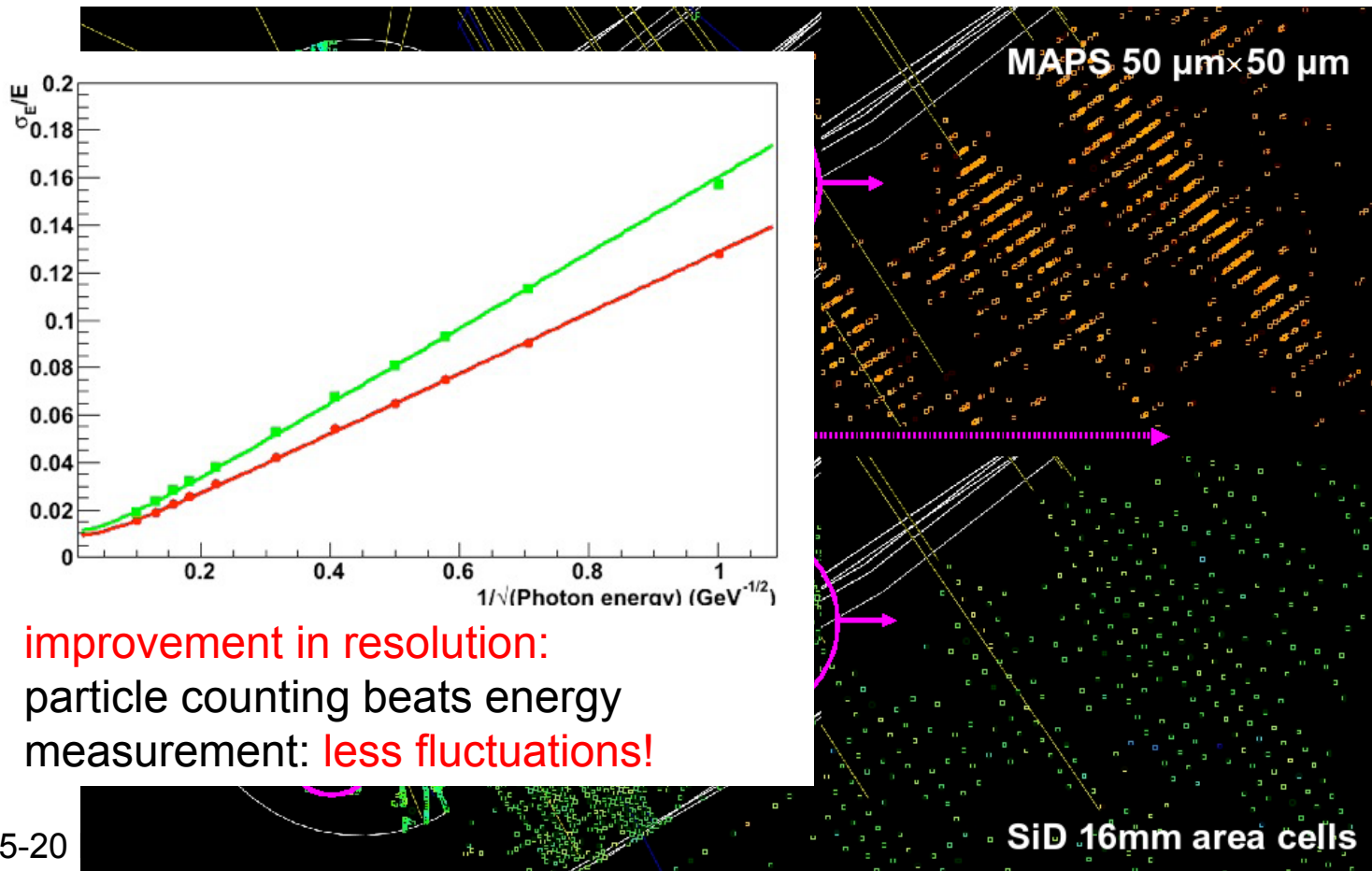**Non-linear behavior for dense showers**

Slope = 23 hits/GeV
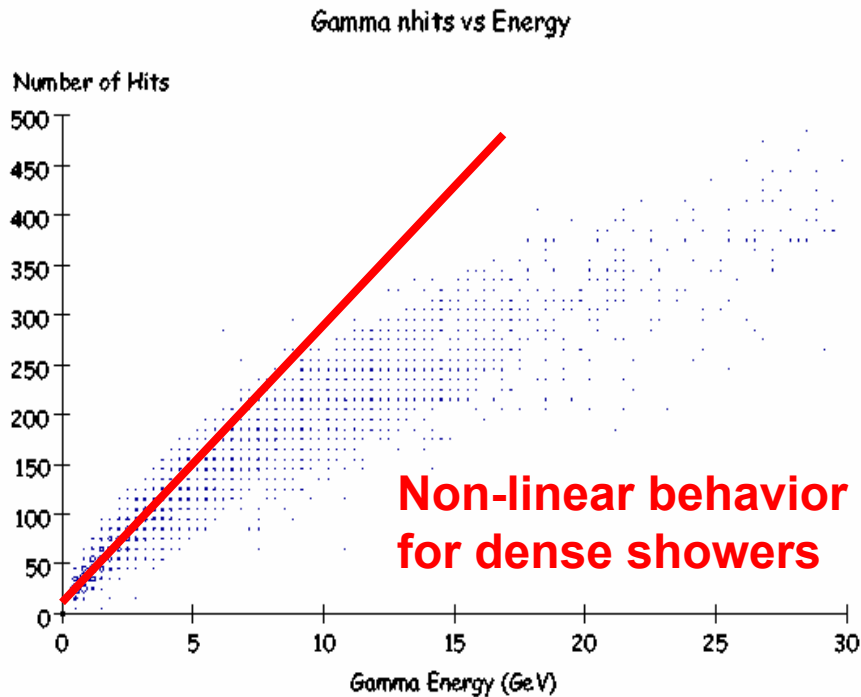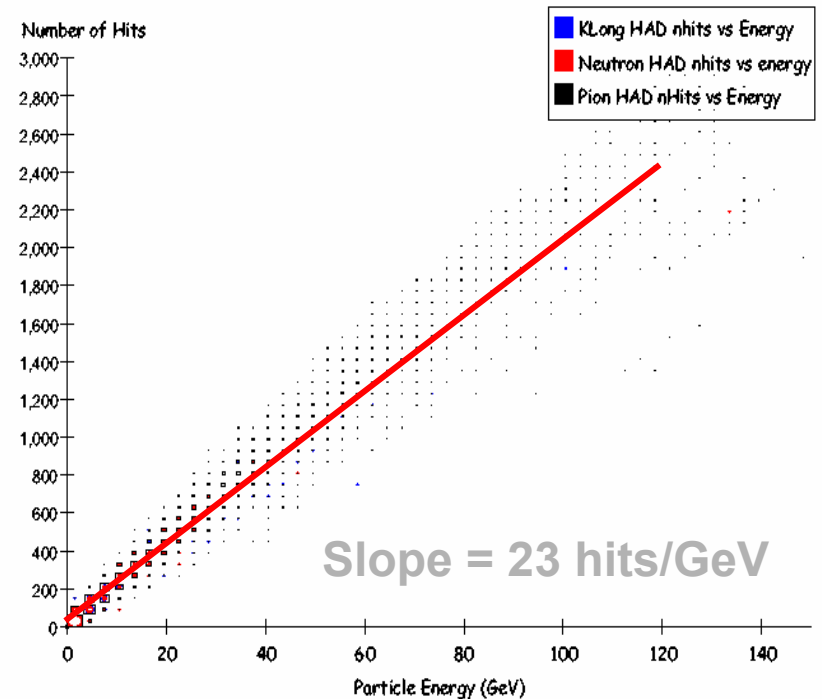
Calorimeter cell size 1x1cm^2

Pushing the Limits of Granularity: A Digital ECAL

Extreme resolution needed to resolve every single particle within an electromagnetic shower:
- Densities of up to 100 particles / mm^2 expected
- Readout granularity of 50 x 50 μm^2 required

MAPS 50 μm×50 μm

SiD 16mm area cells

improvement in resolution:
particle counting beats energy
measurement: less fluctuations!

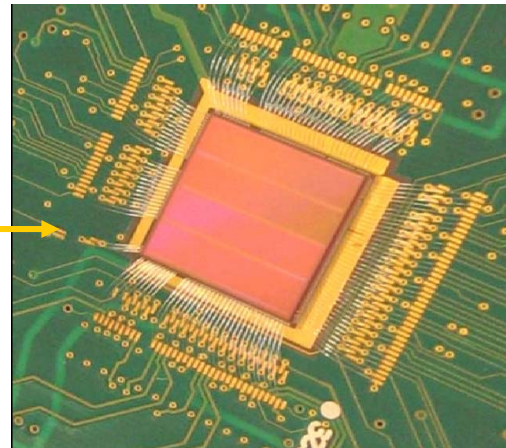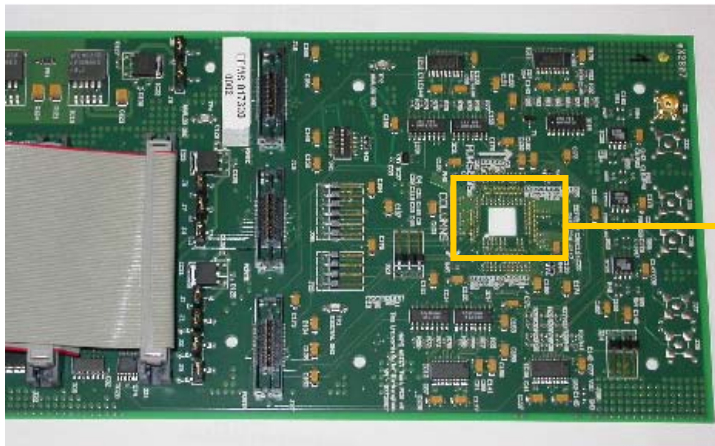# Digital ECAL technology
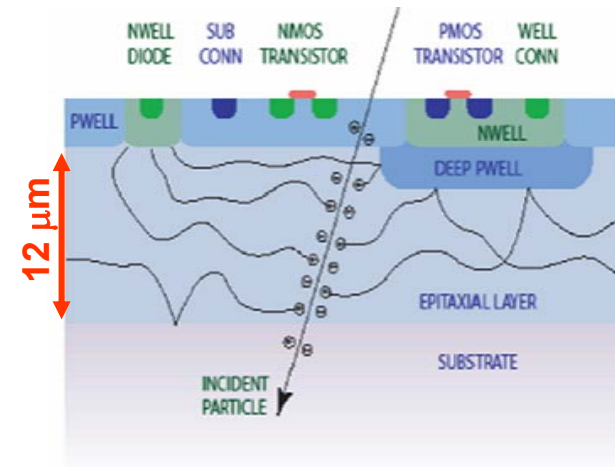
A complete ILC detector would be a Tera-pixel Calorimeter!
The technology: MAPS (Monolithic Active Pixel Sensors)
- A standard CMOS product developed for vertex detectors

• Potentially significant price advantage over high resistivity Si diodes
• Tests of sensor prototypes at CERN in '09: 8.4 x 8.4 mm^2 sensitive area

8.2 million transistors
28224 pixels; 50x50 µm^2

Monolithic Active Pixel Sensors

Digital ECAL technology

A complete ILC detector would be a Tera-pixel Calorimeter!
The technology: MAPS (Monolithic Active Pixel Sensors)
  - A standard CMOS product developed for vertex detectors

• Potentially significant price advantage over high resistivity Si diodes
• Tests of sensor prototypes at CERN in '09: 8.4 x 8.4 mm^2 sensitive area

Electrons 40GeV
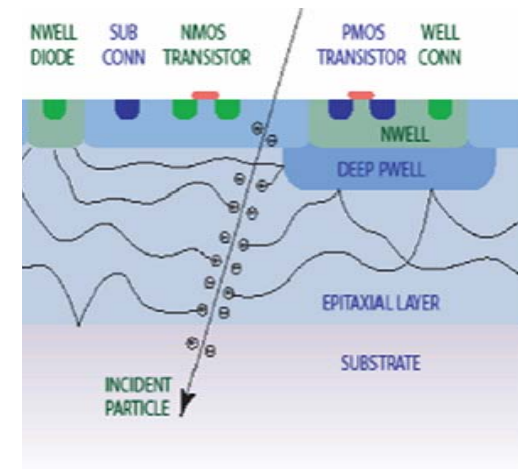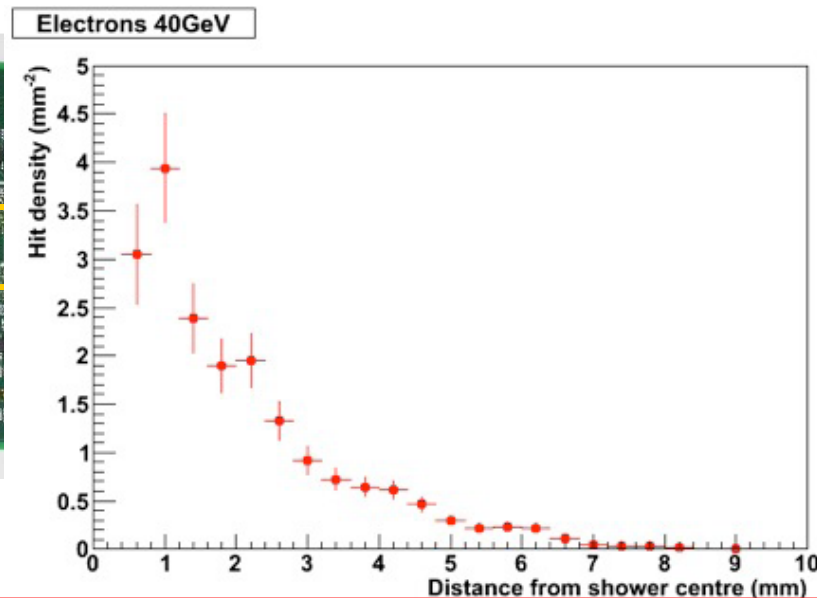
Monolithic Active Pixel Sensors

First measurements of hit density near the shower maximum of em shower
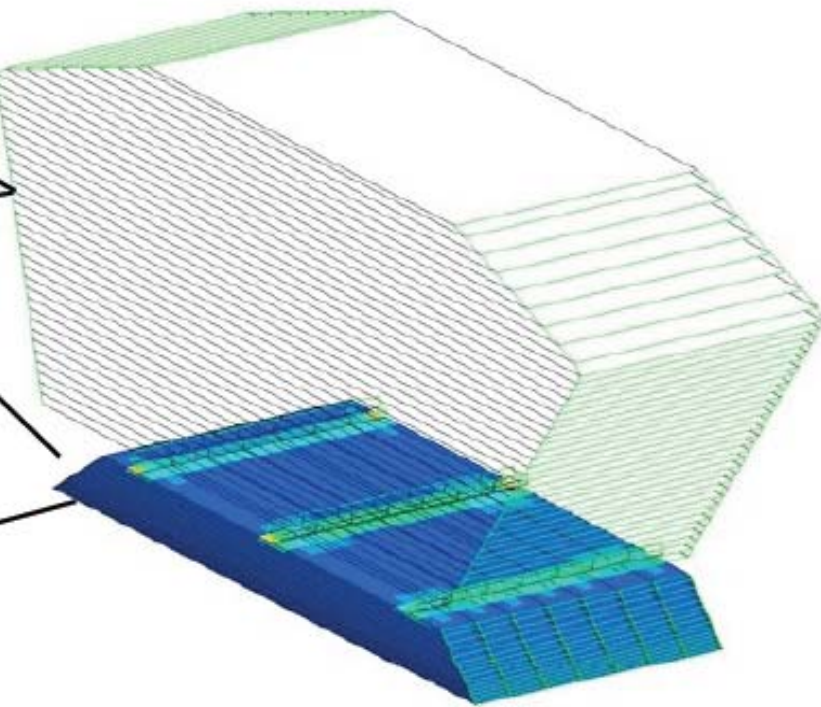
Extreme integration

Next challenge: Demonstrate feasibility and scalability of imaging calorimeters with fully integrated electronics

‣ Meet the space constraints in a real collider detector

Silicon-W ECAL with 5x5mm^2 Si-pad
Active layer including electronics < 2.5mm

Design of a multi-layers barrel ECAL and HCAL

Realistic W mechanical absorber in carbon fiber structure

Talk by D. Jeans

Extreme integration

Next challenge: Demonstrate feasibility and scalability of imaging calorimeters with fully integrated electronics

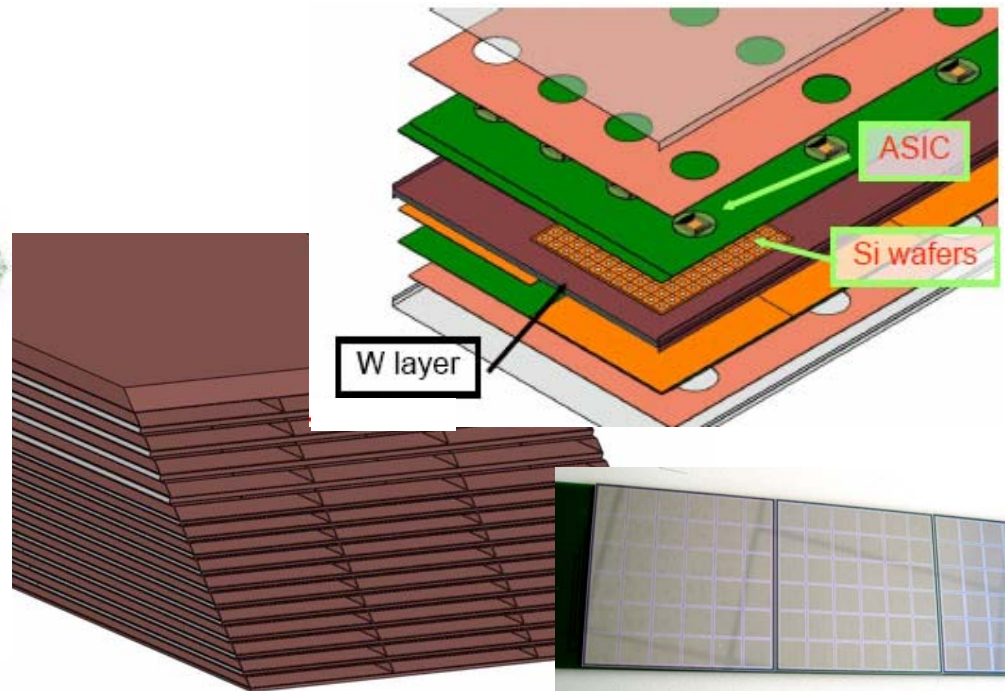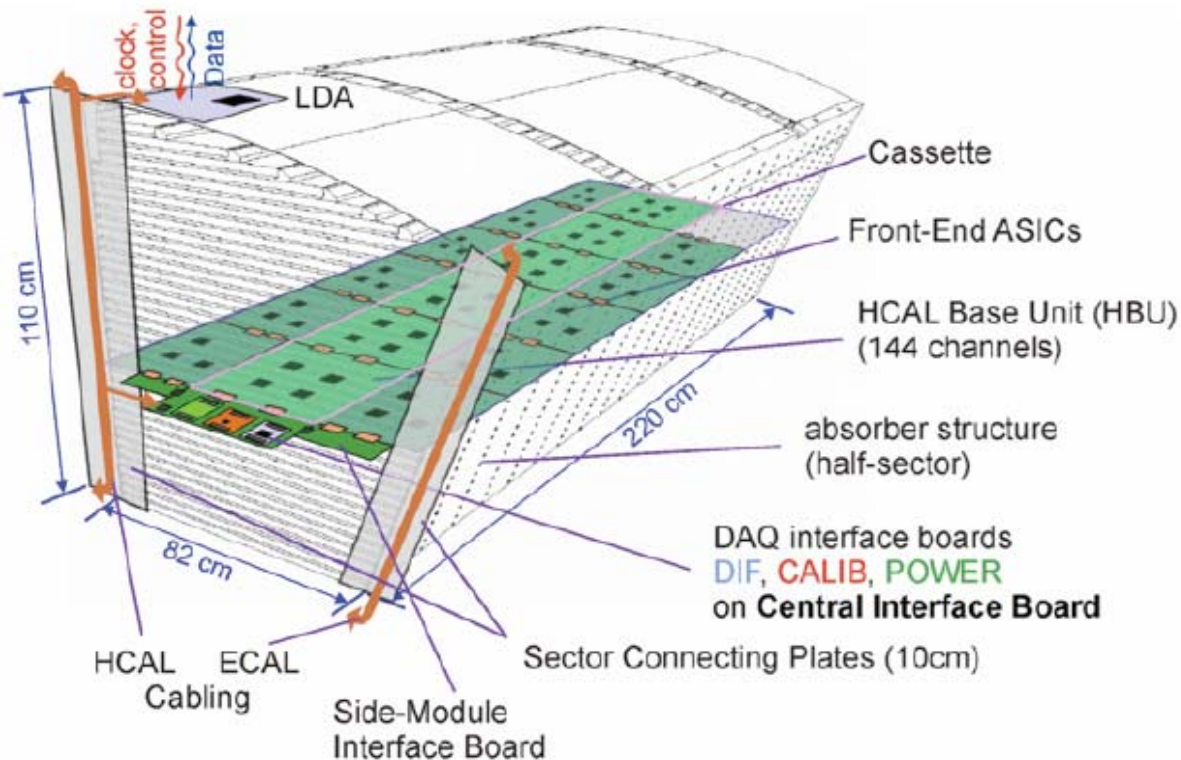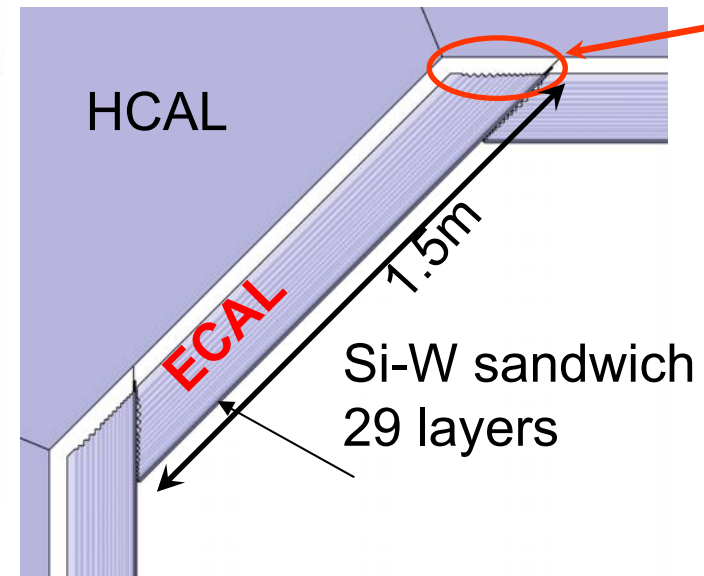‣ Meet the space constraints in a real collider detector

Minimize amount of cables leaving the detector/cracks = Maximize hermeticity

HCAL

ECAL

1.5m

Si-W sandwich 29 layers

Each active layer equipped with readout electronics
➔ Power pulsing

Integrated electronics

New era for chip design:

- Integration of analog and digital parts
- Large dynamic range (15 bits)
- Auto-trigger on ½ MIP   (specific of ILC)
- On chip zero suppress
- Front-end embedded in detector   ➔ **Ultra-low power<<25µW/ch**
- 10^8 channels
- Compactness

- « Tracker electronics with calorimetric performance »
- No chip = no detector !!
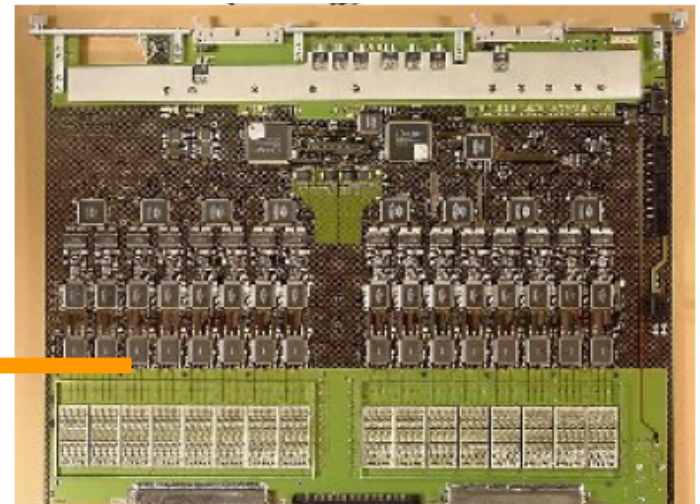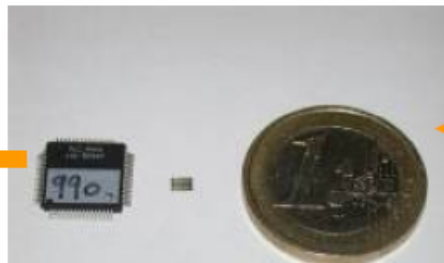
ILC : 25µW/ch	FLC_PHY3 18ch 10*10mm 5mW/ch	ATLAS LAr FEB 128ch 400*500mm 1 W/ch

Time resolution
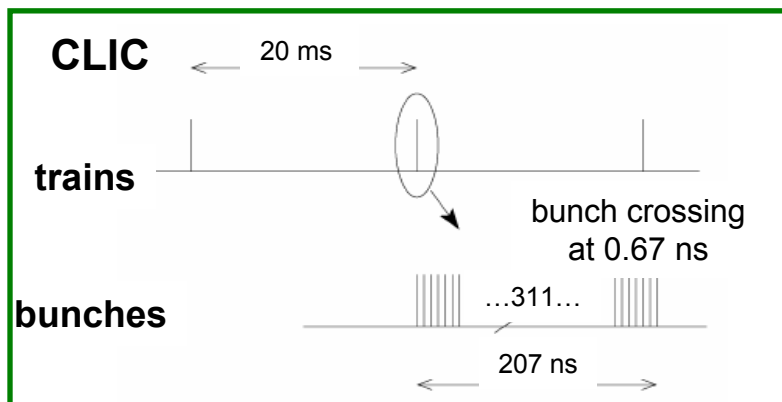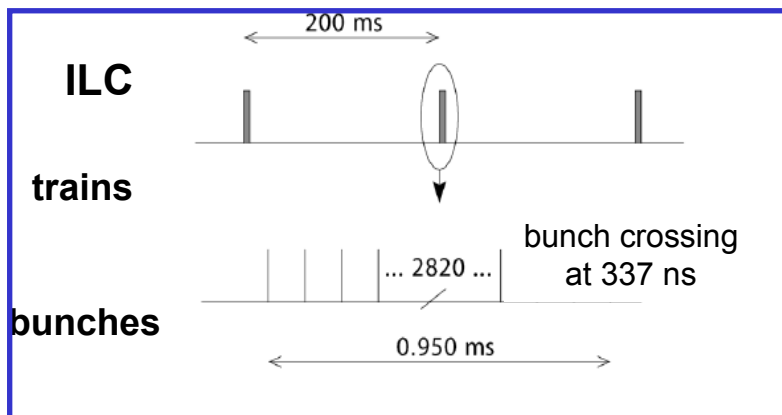
ILC

trains

bunches

- 200 ms
- bunch crossing at 337 ns
- ... 2820 ...
- 0.950 ms

CLIC

trains

bunches

- 20 ms
- bunch crossing at 0.67 ns
- ...311...
- 207 ns

Time res. also relevant to study neutron component of hadronic showers
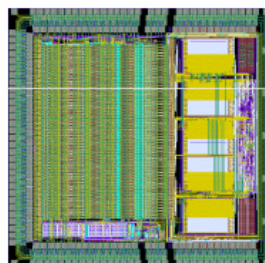
Beyond ILC ➔ CLIC
Higher gradient: 100 MV/m vs 35MV/m
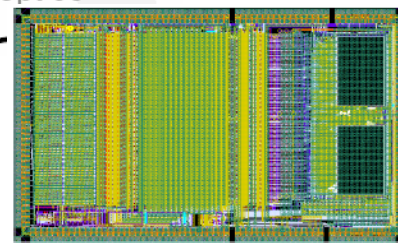Higher cms energy: 3 TeV   vs 500 GeV

➔ Price to pay: 0.5 ns bunch crossing

Time stamp O(10ns) mandatory

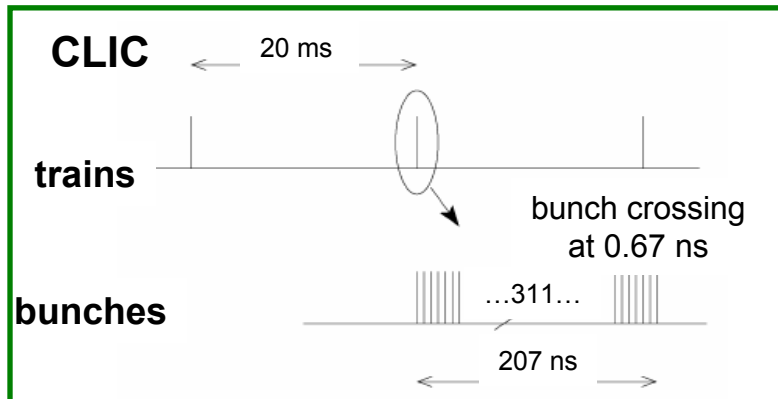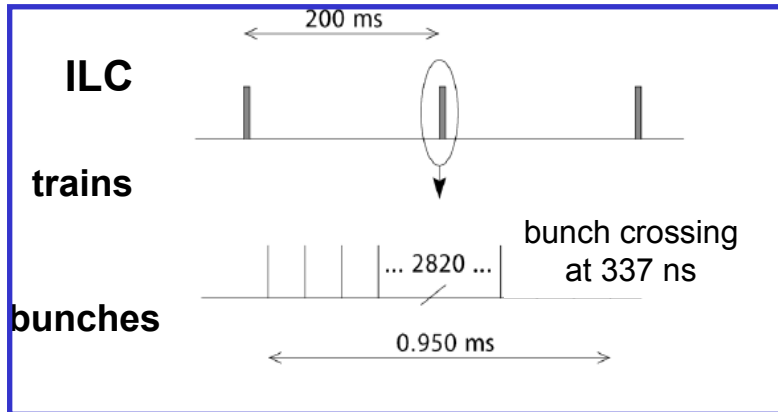TDC integrated in the "ROC" family of chips for future calorimeters
~ 1ns time resolution

HARDROC
Digital HCAL
(RPC or µmegas)
64 ch. 16mm²
Sept 06

SPIROC
Analog HCAL
(SiPM)
36 ch. 32mm²
June 07

Time resolution

ILC

trains

200 ms

bunch crossing
at 337 ns

bunches

... 2820 ...

0.950 ms

CLIC

20 ms

trains

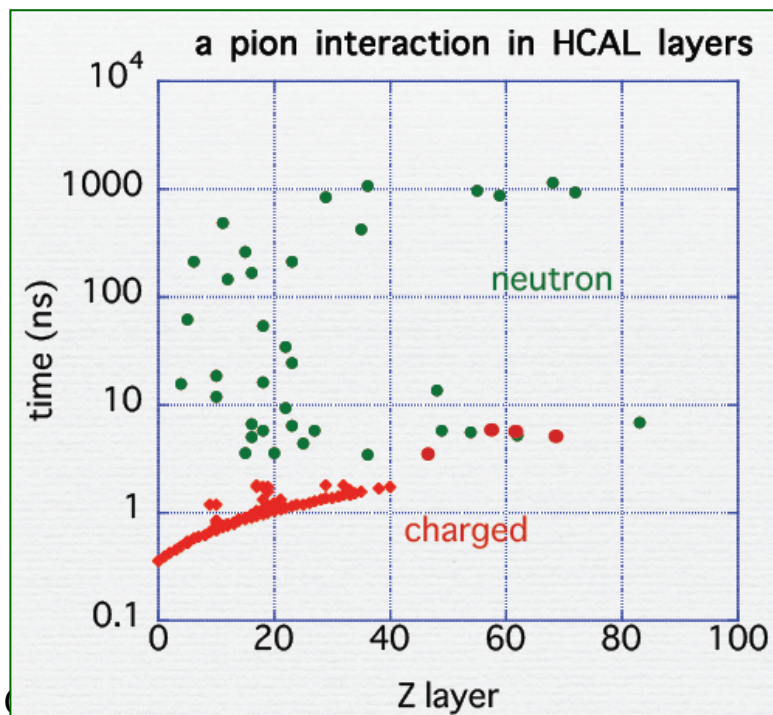bunch crossing
at 0.67 ns

bunches

...311...

207 ns

Beyond ILC ➔ CLIC
Higher gradient: 100 MV/m vs 35MV/m
Higher cms energy: 3 TeV   vs 500 GeV

➔ Price to pay: 0.5 ns bunch crossing

Time stamp O(10ns) mandatory

y of chips

Time res. also relevant to
study neutron component
of hadronic showers

a pion interaction in HCAL layers

10^4

1000

100

time (ns)

10

1

0.1

neutron

charged

0   20   40   60   80   100

Z layer

SPIROC
Analog HCAL
SiPM)
36 ch. 32mm²
une 07

sLHC & CLIC R&D

Calorimetry at sLHC ➜ radiation hard material

- Exchange scintillator with quartz
- Test of different quartz + WLS fiber geometries

Advantages of WLS fiber:

- collect light to photo-detector
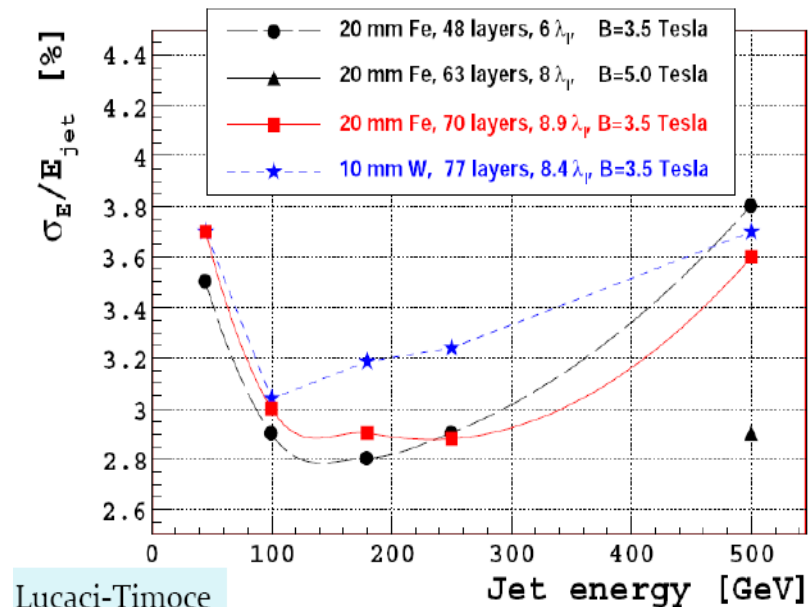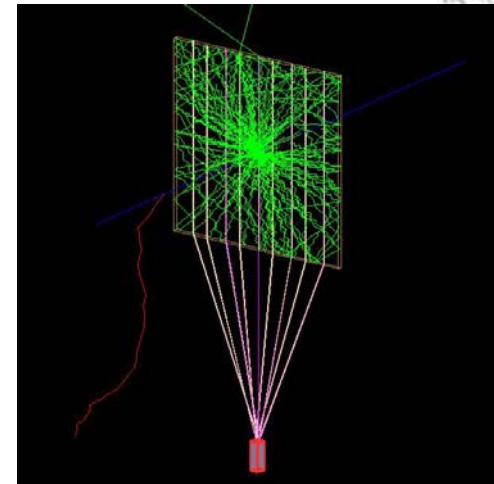- Improves homogeneity of tile

Disadvantages of WLS fiber:

- Degradation of fast Cherenkov signal (<1ns) due to WLS fiber emission

Outlook on future R&D:

- Exploit fast Cherenkov signal + time resolution
- High granularity helps to reduce multiplicity/cell

CLIC: move to Tungsten absorber

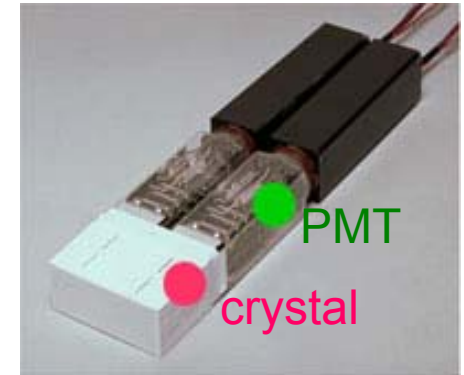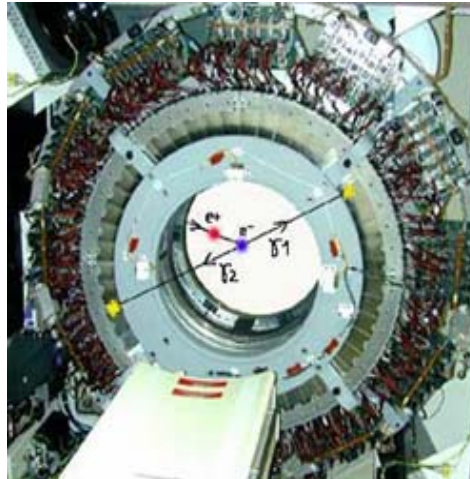Lucaci-Timoce

Calorimeters behind HEP

Positron Emission Tomography

How can a calorimeter save your life? → PET

a commercial PET system
for hospital treatment

the same system without cover

PMT

crystal

basic unit of a PET:
crystal (LSO, BGO) + PMT
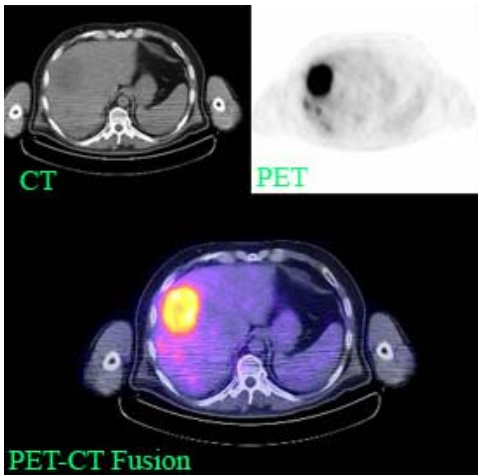
→ Functional (metabolich) pictures of living organs
in addition to Computer Tomography improves high
resolution visualization of anatomic parts

Task: reconstruct 2 γ (511 keV) from annihilation of
positron from a β-emitting tracer
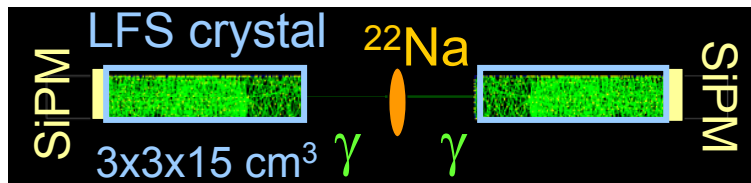   → calorimeter

many talks on this topic tomorrow

New trends in PET calorimeters

High granularity and small calorimeter cells improve space resolution

➔ **Silicon Photomultiplier replace PMT**
- compact system
- low HV & cost

LFS crystal ^{22}Na SiPM
SiPM 3x3x15 cm^3 γ γ

MPPC from Hamamatsu
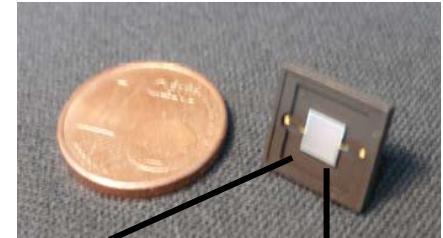
3x3 mm^2 active area

11 % FWHM
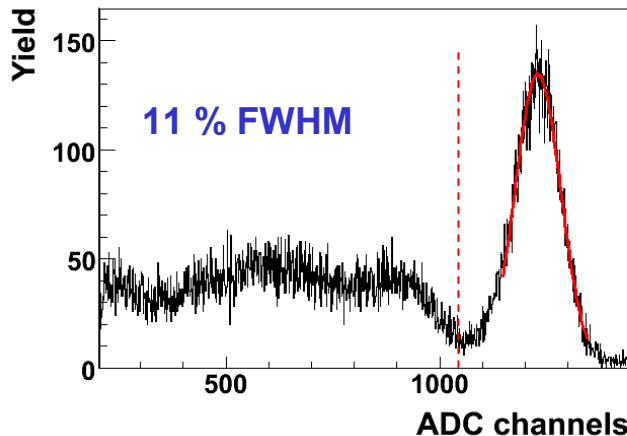
- Good E res. ➔ reduce Compton bg.
- Good t res. ➔ reduce combinatorial bg.

time resolution for coincidence of two channels ~250ps using SiPM readout and dedicated electronics possible

Technology frontier
new products

Extreme granularity

Fiber crystals: ϕ 350um – 3mm
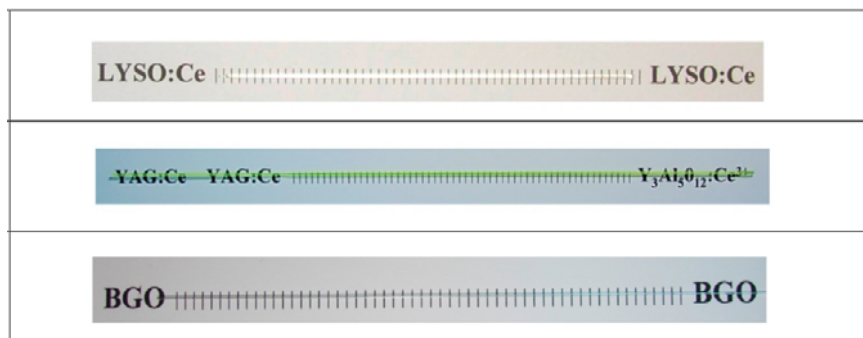
LuAG:Ce Array
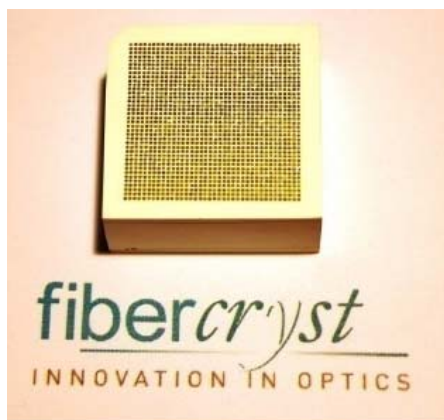

Improve space resolution using smallest crystals individually read out

Extreme integration

new generation of Geiger-mode avalanche photo-detector: integrates SPAD on CMOS

~50 um pixel SPADs arranged in arrays with individual pixel readout
- O(100ps) time resolution on single photon

E. Charbon et al., IEEE (ESSCIRC), Sep. 2009

http://www.everyphotoncounts.com/arrays-linarray.php

Ground based Gamma Ray Astronomy
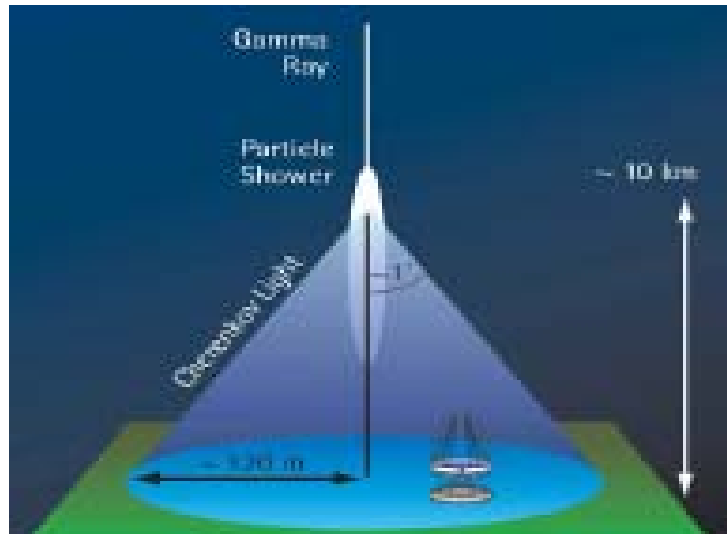
Gamma Ray induces electromagnetic cascade
➜ Relativistic particle shower in atmosphere
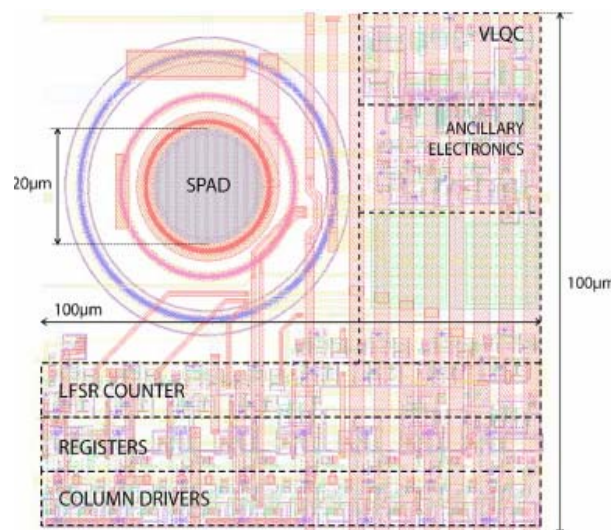➜ Cherenkov light
fast light flash (~ns)
$100 \, \gamma \, / \, m^2$ (1 TeV Gamma Ray)

Next generation: **Cherenkov Array Telescope (CTA**

Example: MAGIC telescope

CAMERA

- Expensive
- Camera composed of 1000 pixels ➜ use PMT for baseline (40% PDE)
- Fast timing response (~1ns) to cope with EAS Cherenkov flashes
- Electronics inside the camera
- Keep low weight

SiPM offer 60% PDE at 400nm
+ improvements with lower fill factor

Talk by O. Grimm

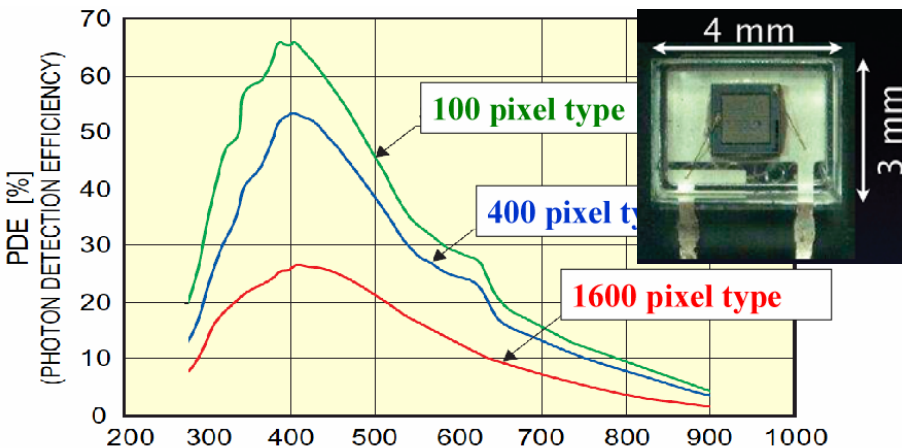# Positron Electron Balloon Spectrometer

Goal: Measure the cosmic ray positron fraction with a balloon borne spectrometer

Motivation: Indirect search for dark matter

Talk by G. Yearwood
Poster by F. Zehr

Requirements (calorimeter):
- Excellent proton suppression of $O(10^6)$
- Total payload weight < 2t
- Total power consumption < 1000W

Electromagnetic calorimeter:
80 x (1mm Pb + 8x1 mm^2 scintillating fibre + SiPM) = 14.3 X0, weight: 550kg

3 mm

Time-of-Flight system (TOF):
2 x 2 x 5 mm^3 scintillator, SiPM readout; trigger system!

Transition Radiation Detector (TRD):
2 x 8 x (2cm fleece radiator + 6mm straw tube Xe/CO_2 80:20)

TOF 2 layers 90° crossbred
rasnik system
TRD modules 2x8 layers
solar panels
magnet
support structure
TOF 2 layers 90° crossbred
Radiator

95x8=760mm
1mm Pb, 8x8mm scintillator
76 cm
ECAL
10 superlayers 90° crossbred

support tube
Crates
16 cm

cutout view of ECAL in Geant4 simulation

Proton rejection

e/p separation based on different longitudinal shower shape at a given particle energy (spectrometer) ➔ extremely high granularity
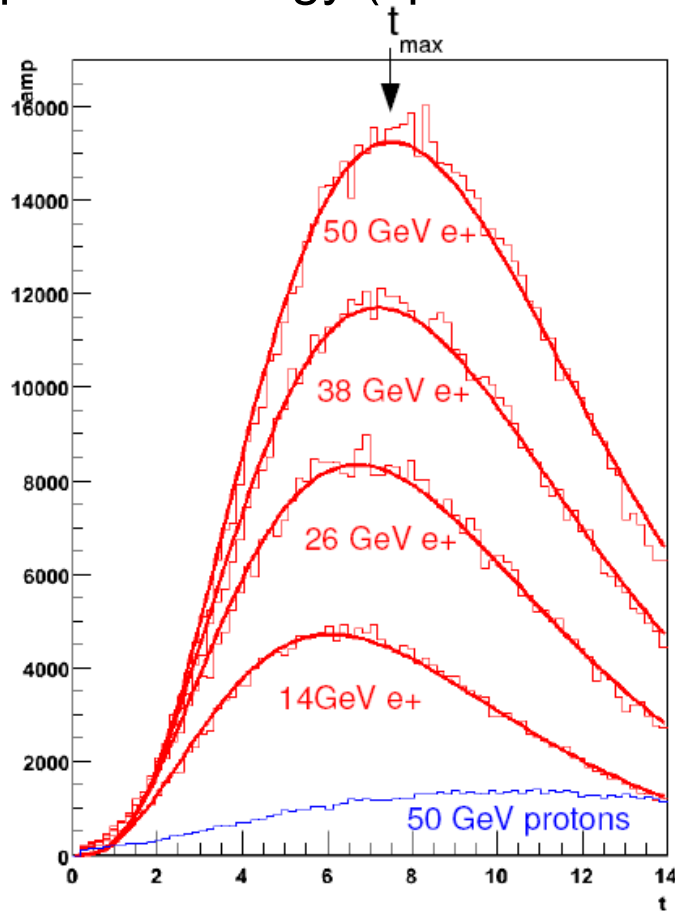
$$\frac{dE}{dt} = E_0 \frac{b^{\alpha+1}}{\Gamma(\alpha+1)} t^\alpha e^{-bt} \quad t=x/X_0$$

longitudinal shower profiles
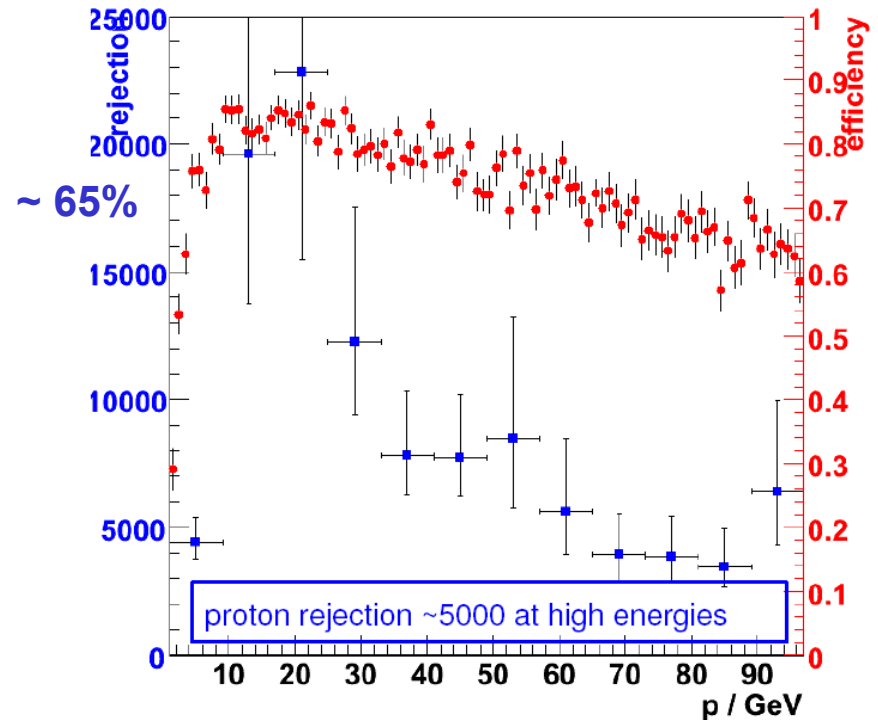
Simulated 40k positrons and 1700k protons

proton rejection ~5000 at high energies

intrinsic resolution limited by high energy π^0 production (p → pπ^0X) in front of or in first layers of ECAL

Calorimeter for ββ0ν search: The Bolometer

Bolometer operating principles:

heat bath

$$\Delta T = E/C \cong 0.1 \text{ mK}$$

Low Temperature

weak thermal coupling

thermometer
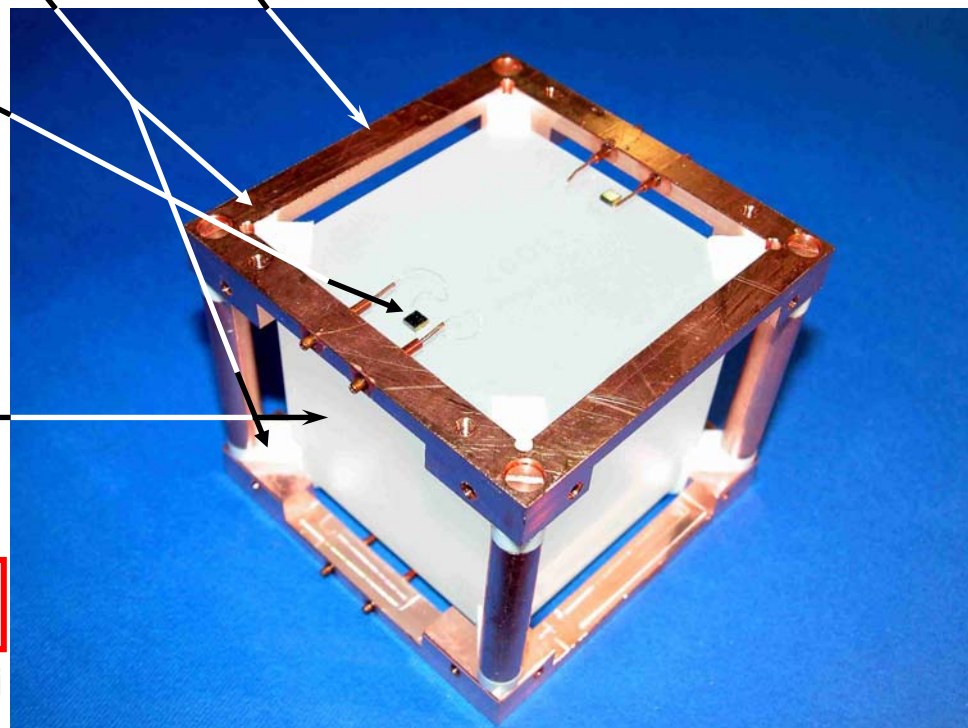
Teflon pieces

Cu holder

Absorber material TeO_2 low heat capacity large crystals available radiopure

NTD Ge sensor
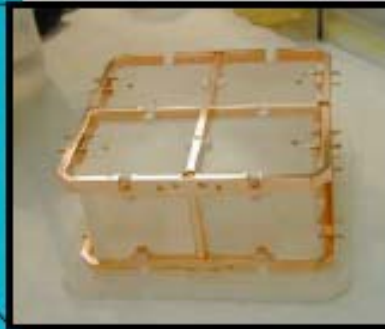
absorber crystal

particle of interest

TeO_2 crystal

E resolution (FWHM) ~ keV possible

Cuoricino experiment @ Gran Sasso

Currently the largest bolometer in the world

11 modules, 4 detector each,
crystal dimension: 5x5x5 cm^3
crystal mass: 750 g
44 x 0.79 = 34.76 kg of TeO$_2$

Encased in a lead shield, nitrogen box, neutron shield, and Faraday cage

2 modules x 9 crystals each
crystal dimension: 3x3x6 cm^3
crystal mass: 330 g
18 x 0.33 = 5.94 kg of TeO$_2$
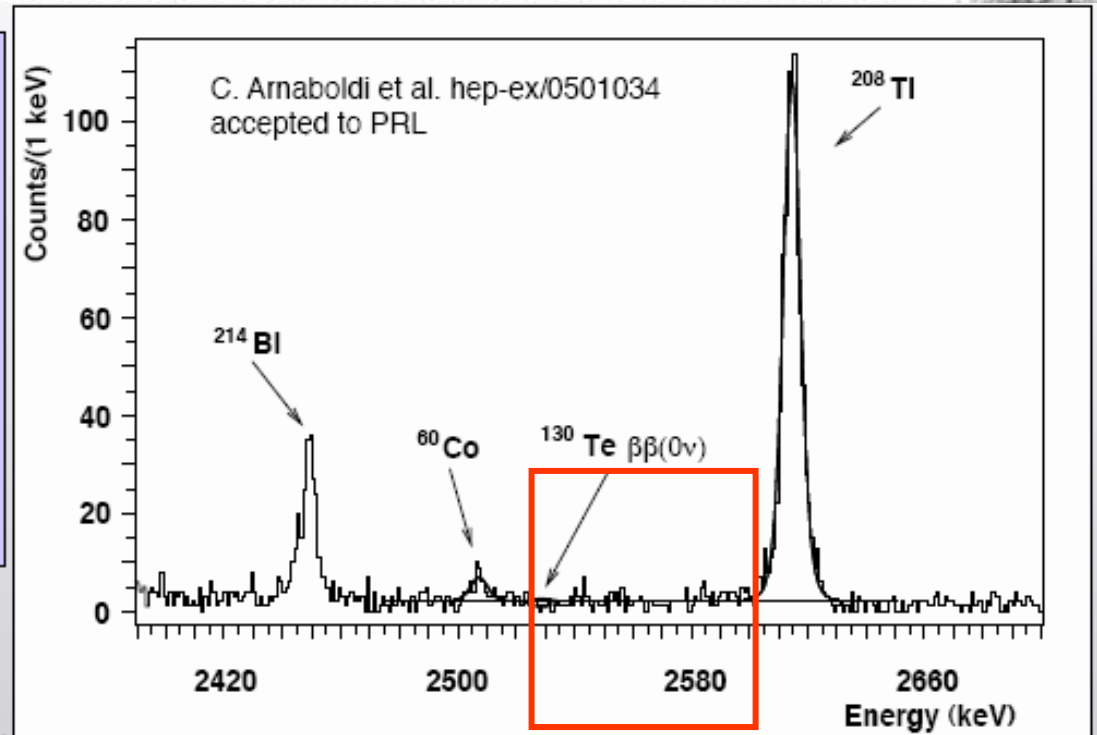
Total detector mass: 40.7 kg TeO$_2$ $\Rightarrow$ **11.64 kg ^{130}Te**
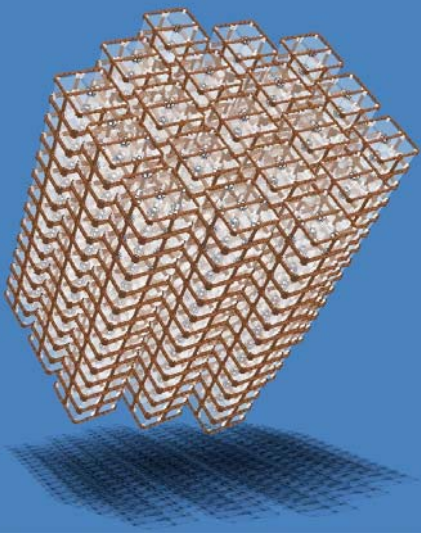
Cuoricino limit on $\beta\beta0\nu$

Exposure
= 10.85 kg y

Resolution:
FWHM at 2615 keV
= 9.2 ± 0.5 keV

Background:
In the $\beta\beta0\nu$ region
= 0.18 ± 0.01 counts /(keV kg y)

C. Arnaboldi et al. hep-ex/0501034
accepted to PRL

^{208}Tl

^{214}Bi

^{60}Co

^{130}Te $\beta\beta(0\nu)$

Counts/(1 keV)

Energy (keV)

...m

...lat+^{60}Co (2505)

...0-2560 keV

...on parameter variation

...nction with individual

...ion

No peak found

$\tau^{0\nu}_{1/2} > 1.8 \times 10^{24}$ y at 90% C.L.
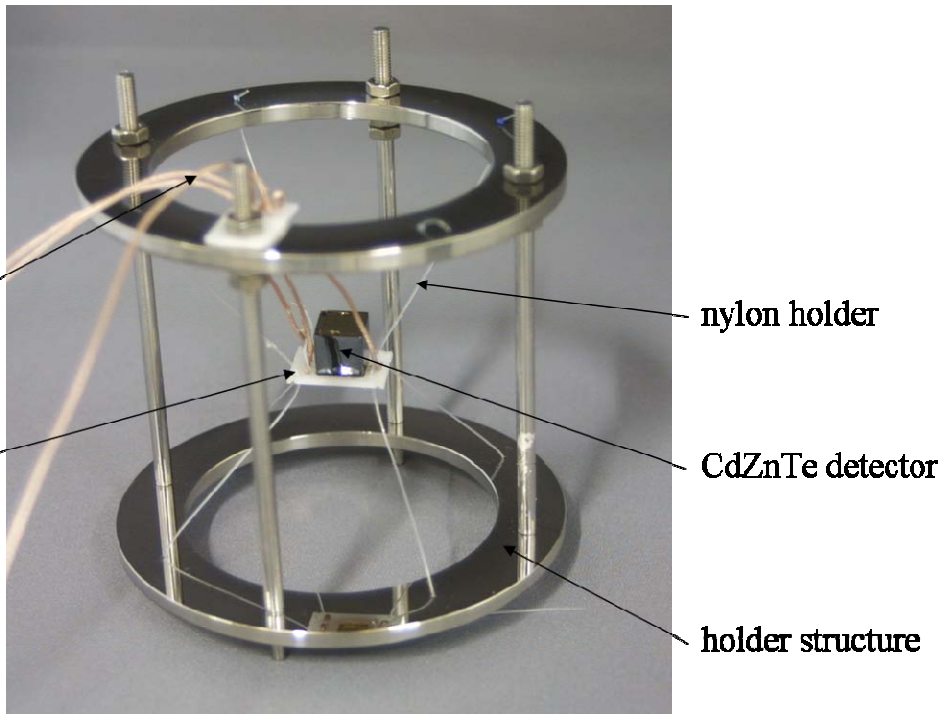
2.94

$m_\nu < 0.2 - 1.1$ eV

CUORE will follow with: 988 TeO$_2$ bolometers cubes
5 cm^3 with a mass of 750 g each.

New sensor materials: CdZnTe

New trends in $0\nu\beta\beta$ decay detectors
➜ The COBRA experiment

- nylon holder
- CdZnTe detector
- holder structure

- detector based on CdZnTe semiconductor
- operated at room temperature
- high density of the crystal provides excellent stopping power
- detector array under design:
        ~6400 crystals
        of 1 cm^3 size (~6.5g)
        for a total of 400 kg

Conclusions

- Calorimetry is a field developed over more than a century, still vital and in continuous evolution

- Calorimetry at the technology frontier drives the development of new materials, new photo-detectors, new electronics, …, new analysis techniques, new ideas

- Present key issues for calorimetry:
  - Extreme segmentation (Imaging calorimeters)
  - Extreme integration (maximum hermeticity)
 - Compensation in limited volume (Pflow/ dual-readout)

Thank you for your attention

BackUP

New Type of SiPM at MPI: SiMPL

- **Simplified SiPM (SiMPL):**

  - Common cathode and n^+ backside: significantly reduced surface obstructions

  - Anode is an internal node within Si bulk

  - Bulk region beneath the anode acts as vertical resistor, shielded by the anode from depletion

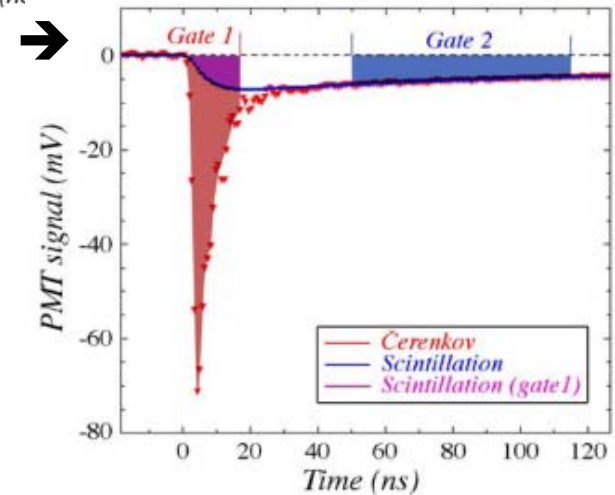 - Gap regions are depleted and isolate the individual resistors
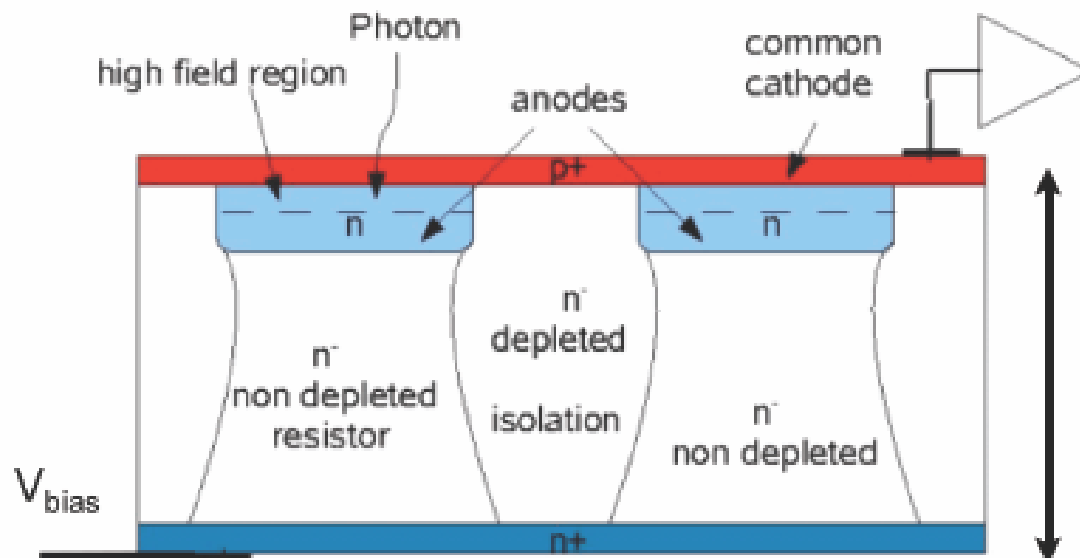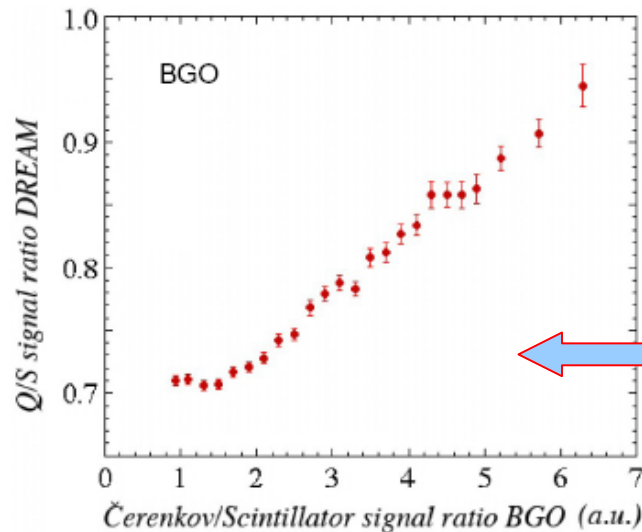

The Challenge:
resistor matching via Si thickness (does not work with usual wafer thickness)

thin Si (or EPI material)

Cherenkov light measurements
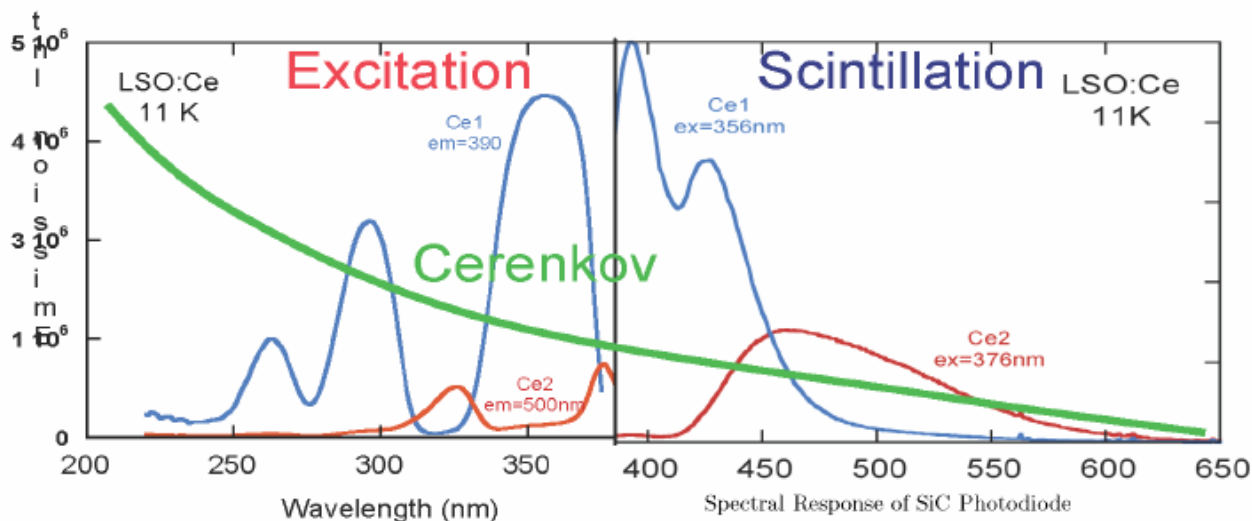
Average Time structure for 50 GeV electrons
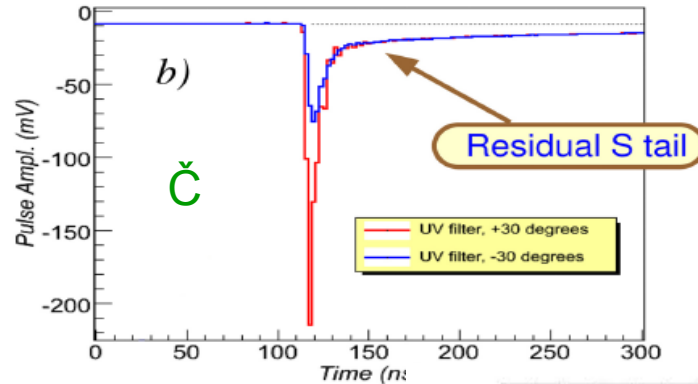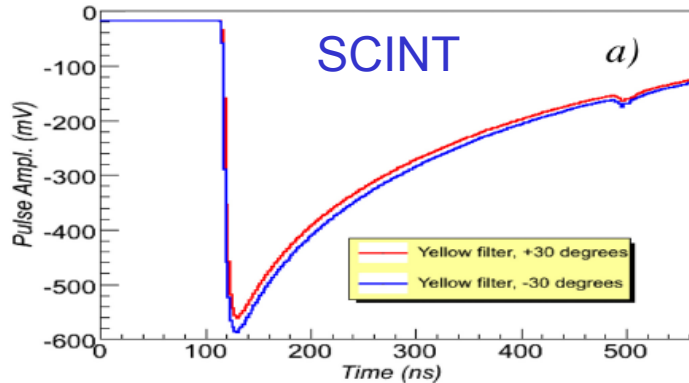
C/S ratio event by event: integrate charge Q1 ➔
collected in the Gate1, and Q2 collected in Gate2

The variable C/S on BGO is able to measure the
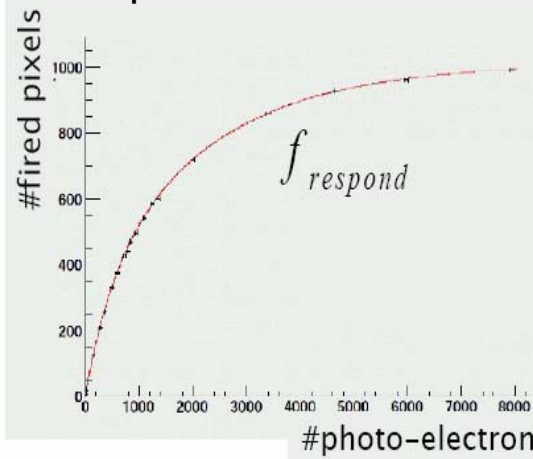em component of the shower on the Calorimeter

Detecting UV light

New Developments in Silicon Carbide avalanche photodiodes QE of 60% peaking at 280nm

Perfect for Cherenkov

# Importance of monitoring/calibration system in a SiPM based calorimeter

SiPM response is non-linear

$f_{respond}$

#fired pixels

#photo-electron

Single Photon Response

pedestal
1 pixel
2 pixels

gain

Conversion ADC ch.→pixels

Calibration system should deliver:
-Low intensity light for SiPM Gain calibration
-High intensity of light for saturation monitoring
-Medium intensity light for monitoring T,V variations

AHCAL layer = 216 tiles
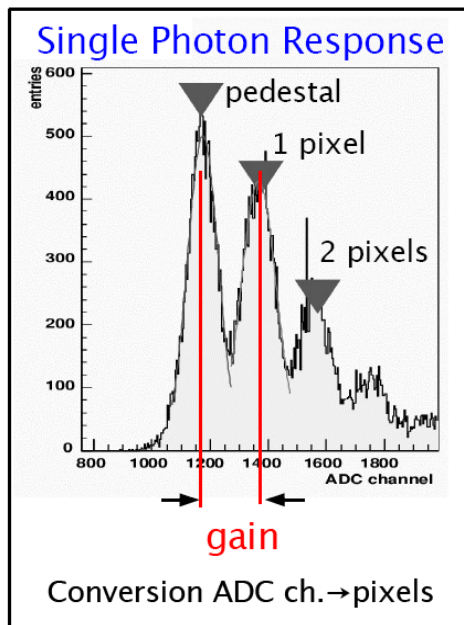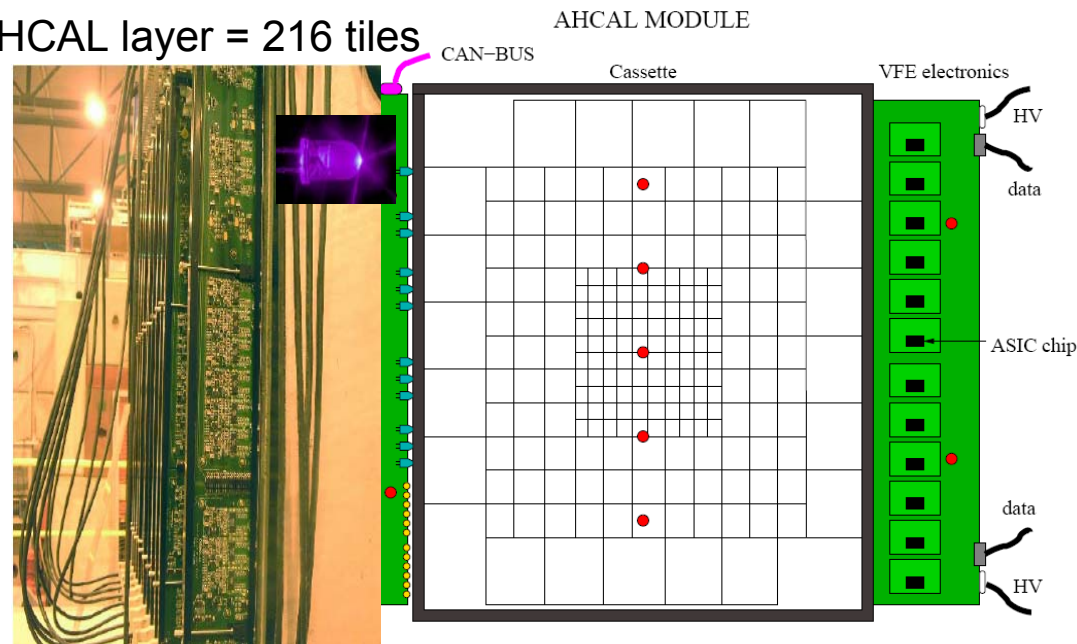
Light intensity for 8000 channels within factor 2
>94% calibration efficiency on full calorimeter

ECAL discussion

- Dynamic range : electronics & Photon sensor
  MPPC non linearity

e+e- > e+e- at 500GeV
at least 15bits ADC

JCBrient   dE / cell (MIP)

1600 pix Results

w = 50 ns

24 ns

16 ns

8 ns

V_{bias} = 71.0 V
V_{bias} = 71.5 V
V_{bias} = 72.0 V

MPPC output (pixels)

Light input (photoelectrons)