CALICE Testbeam Studies and Plans

Georgios Mavromanolakis (for the CALICE Collaboration)

Cambridge University and Fermilab

Outline

- **General - Introduction**
- **High granularity calorimetry and CALICE**
- **Testbeam program in 2005 - 2006**
- **Plans for 2007 - 2008**
- **Summary**

Particle flow paradigm

- **try to reconstruct every particle of the event in order to improve the jet energy resolution**

- **visible energy of a typical jet**

  : $\sim$ 60 % charged particles

  : $\sim$ 30 % photons

  : $\sim$ 10 % neutral hadrons

- **particle flow step-by-step**

  : use tracker to measure charged particle momentum

  : use ECAL to measure photon energy

  : use HCAL+ECAL to measure neutral hadron energy

  : use tracker+ECAL+HCAL to disentangle charged from neutrals

Jet energy resolution

particles in jet	fraction of energy in jet	detector	single particle resolution	jet energy resolution
charged particles	60 %	tracker	$\frac{\sigma_{p_t}}{p_t} \sim 0.01\% \cdot p_t$	negligible
photons	30 %	ECAL	$\frac{\sigma_E}{E} \sim 15\%/\sqrt{E}$	$\sim 5\%/\sqrt{E_{jet}}$
neutral hadrons	10 %	HCAL+ECAL	$\frac{\sigma_E}{E} \sim 45\%/\sqrt{E}$	$\sim 15\%/\sqrt{E_{jet}}$

- $\sigma_{jet} = \sigma_{charged} \oplus \sigma_{photon} \oplus \sigma_{neutral} \oplus \sigma_{confusion}$

  : confusion term comes from misassignment of energy to wrong particles due to double-counting, overlapping clusters, bad track-shower reconstruction etc

  : improve confusion term by having

  better pattern recognition $\rightarrow$ highly granular calorimetry

Challenge

- **role for calorimeters**

  : not so much as efficient energy measurement devices
  but mostly as

  imaging detectors to provide excellent 3D reconstruction of showers
  for very efficient pattern recognition and particle separation

- **strong interplay between hardware and software**

CALICE Collaboration

- : formed to conduct the R&D effort needed to bring
  initial conceptual designs for the **calorimetry** to a final proposal
  suitable for an experiment at the future linear collider

- : 30+ institutes from 10+ countries from Europe, America, Asia
  organic growth, open invitation to join

CALICE Collaboration

- **objectives**

  : build and operate very highly granular calorimeters and demonstrate proof of principle

  : do extensive individual and combined testbeam studies towards detector optimisation

- **roadmap**

  : debug technology/detector concept(s)

  : detector characterisation

  : test-validate-improve simulation codes and shower packages

  : test "particle flow paradigm", interplay between hard/soft-ware

Concepts to study

- **Si ECAL**

  : Si pads and W absorber, **1 $\times$ 1 cm^2 granularity**,
  prototype with 30 layers, 24 X_0, total: $\sim$ 10000 channels

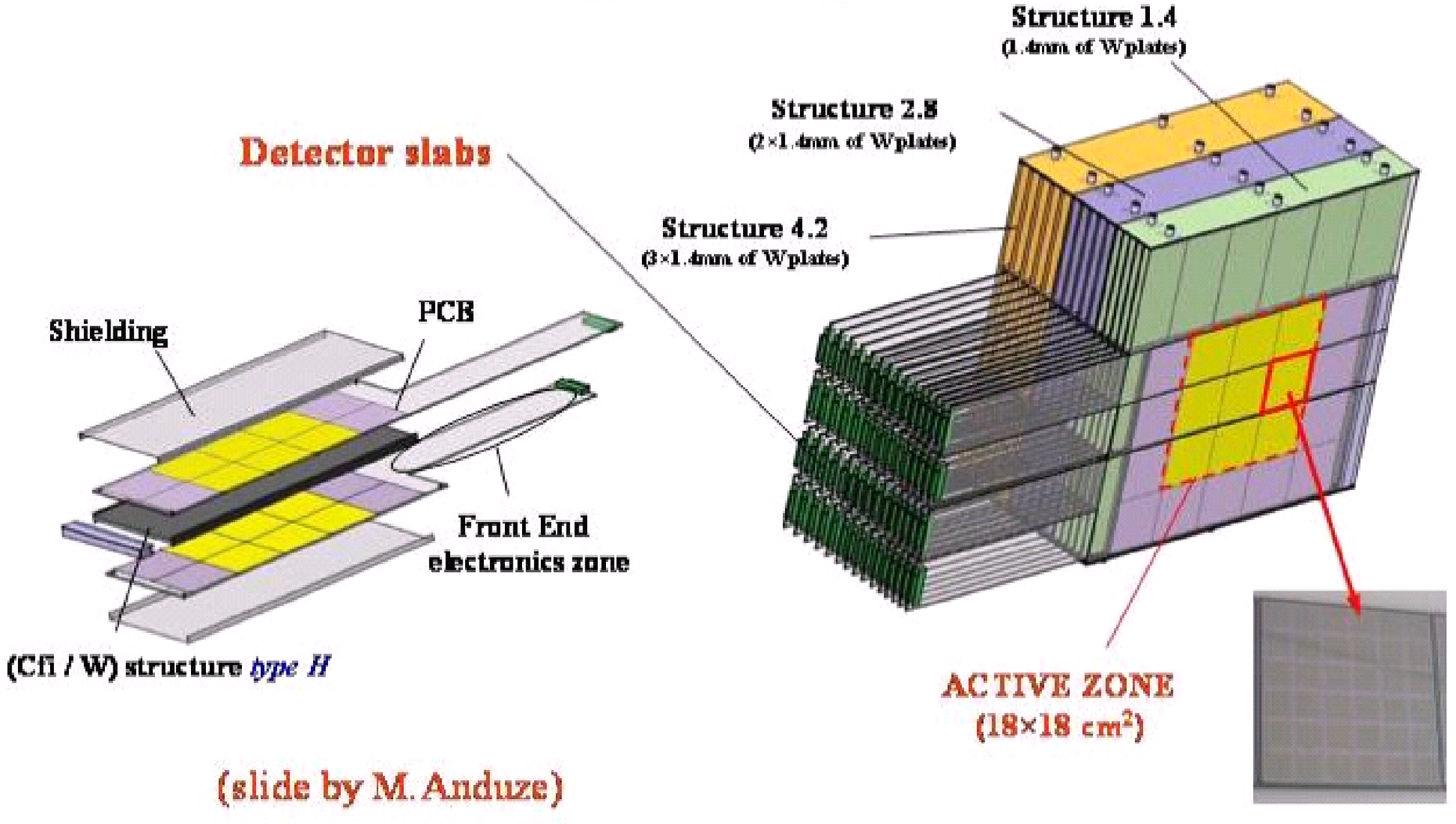
- **scint.tile HCAL**

  : scintillator tiles and steel absorber, central part with **3 $\times$ 3 cm^2 granularity**,
  1 m^3 prototype with 40 layers, $\sim 4.5\ \lambda_I$, total: $\sim$ 8000 channels
  readout by SiPMs

- **scintillator strip ECAL**

  : scint.strips and W absorber, **1 $\times$ 1 cm^2 effective granularity**,
  prototype with 27 layers, 27 X_0, total: $\sim$ 2000 channels
  readout by MPPCs

CALICE ECAL prototype



(slide by M. Anduze)

full Si/W prototype (24 X_0)

- 30 layers $\times$ 18 cm $\times$ 18 cm, interleaved with 0.5 mm Si pads
- W absorber, 10+10+10 layers, 1.4 mm:2.8 mm:4.2 mm thick per respective layer
- readout by **1 $\times$ 1 cm^2 cells, total: 9720 channels**

ECAL board

6 active wafers

- 36 silicon PIN diodes each
  $\longrightarrow$ 216 channels per board.
- Diode size: $1 \times 1\,\mathrm{cm}^2$.

Calibration chips

- 2 calibration switches chips.
- 6 calibration channels per chip.
- 18 diodes per calibration channel.

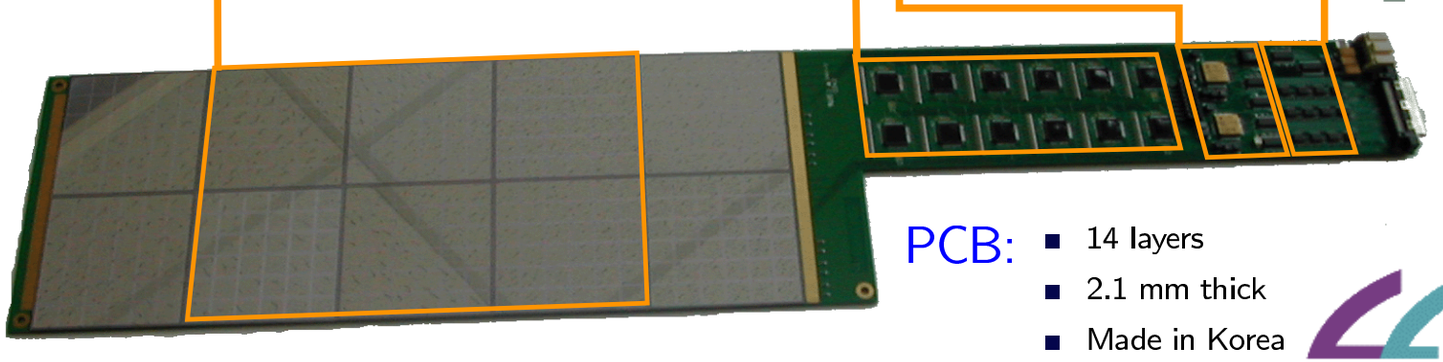
Front-End chip

12 FLC_PHY3 front-end chip

- 18 channels / chip
- 13 bit dynamic range

Line buffers

- To DAQ part
- Differential.

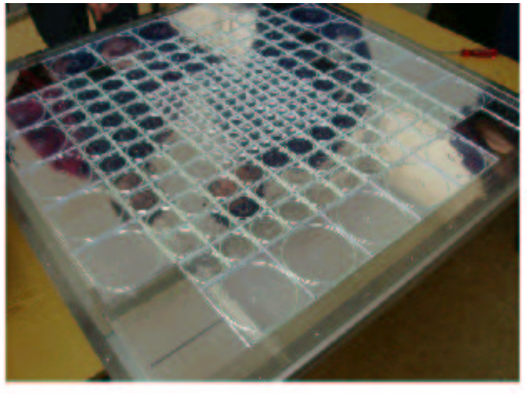


PCB:

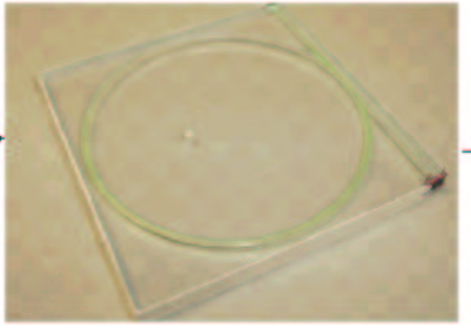
- 14 layers
- 2.1 mm thick
- Made in Korea

(J.Fleury)

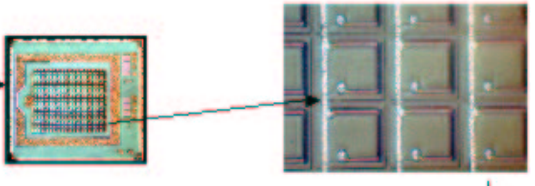
HCAL readout chain



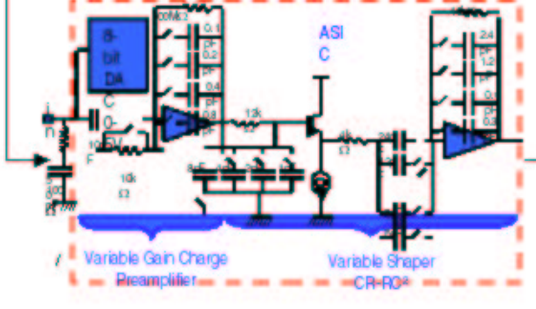
Read out 216 tiles/module
~8000 channels



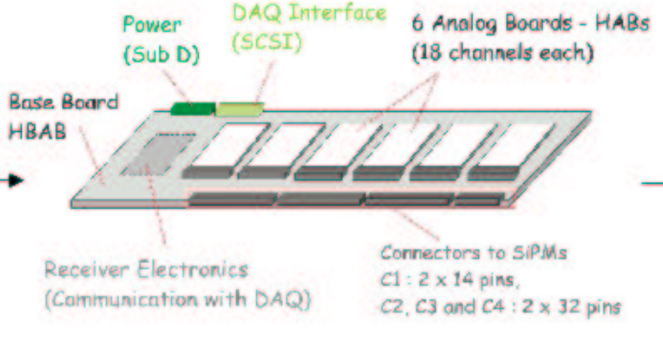
Single tile readout with
SiPM



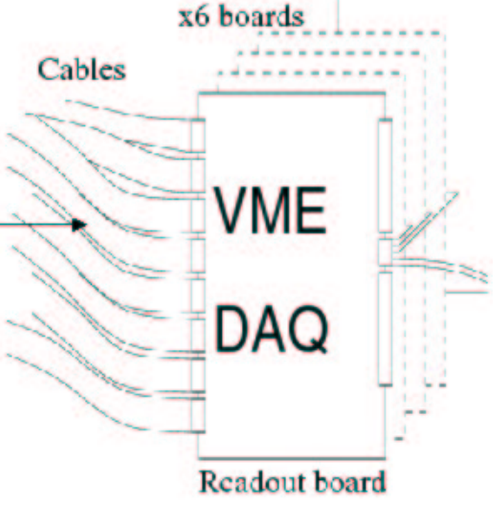
SiPM: pixel device
operated in Geiger mode



ASIC: amplification +
shaping + multiplexing



VFE: control 6 ASICs connect
to SiPM



(M.Groll)

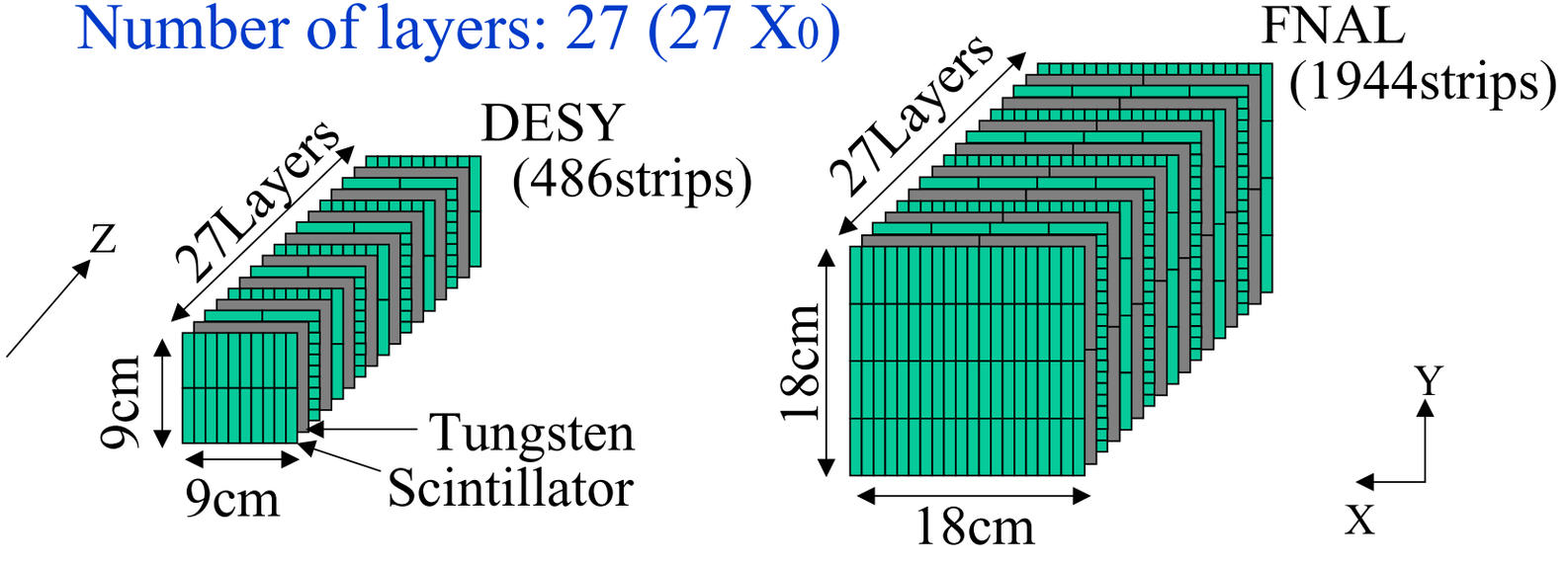
Scintillator Strip ECAL

Prototype ECAL - MPPC readout

Tungsten:3.5mm Sci. strip:3mm

Strip size: 1cm (width) x 4.5cm (length)

Number of layers: 27 (27 X_0)



Cross section 9cmx9cm Test@DESY(This winter)

-> In EM shower (Non linearity of MPPC)

Cross section 18cmx18cm Test@Fermilab(2007)

-> In multi particle injection / Pi0 reconstruction

(slide by T.Takeshita)

Concepts to study (continued)

- **digital HCAL RPC**

  : Resistive Plate Chambers and steel absorber, **1 $\times$ 1 cm^2 granularity**, 1 m^3 prototype with 40 layers, $\sim 4.5\ \lambda_I$, total: **400000 channels**

- **digital HCAL GEM**

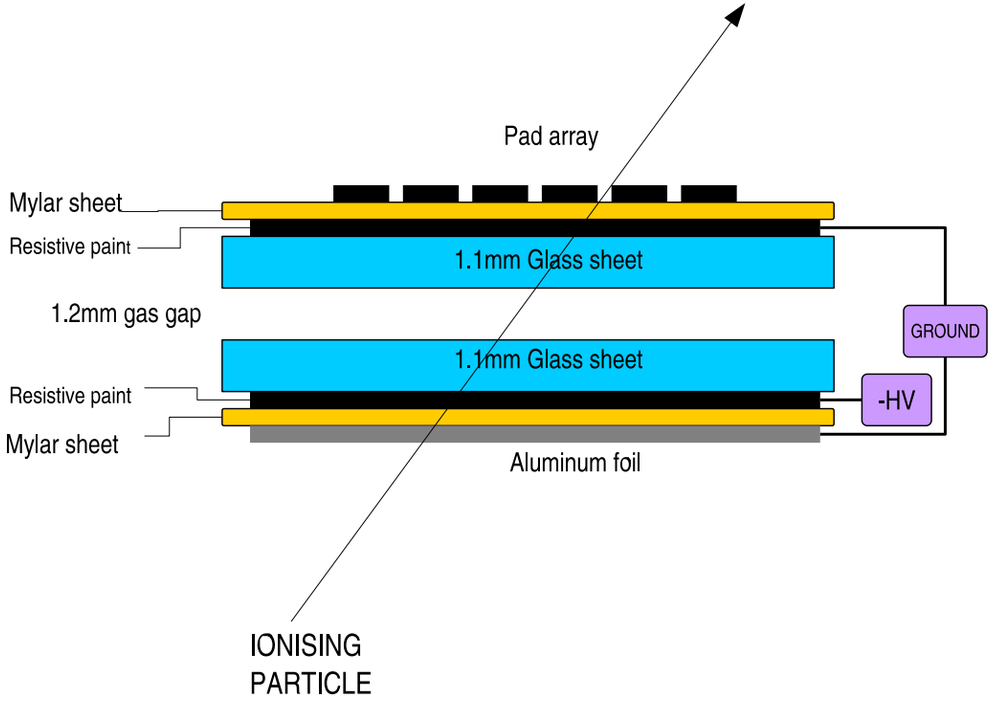
  : Gas Electron Multipliers and steel absorber, **1 $\times$ 1 cm^2 granularity**, 1 m^3 prototype with 40 layers, $\sim 4.5\ \lambda_I$, total: **400000 channels**

- **digital HCAL with microMegas**

  : layers equipped with "Micro mesh gaseous structure" chambers, readout by pads or strips

Digital Hadron Calorimetry

Resistive Plate Chamber



Gas Electron Multiplier

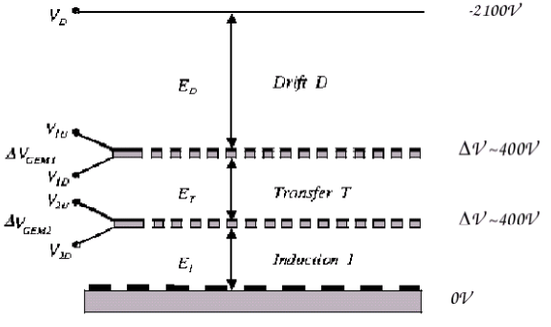


Fig. 1: Schematics of a double-GEM detector.

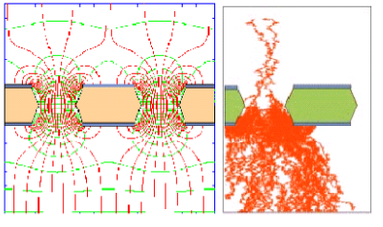
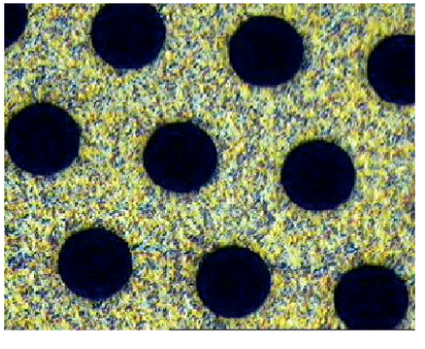


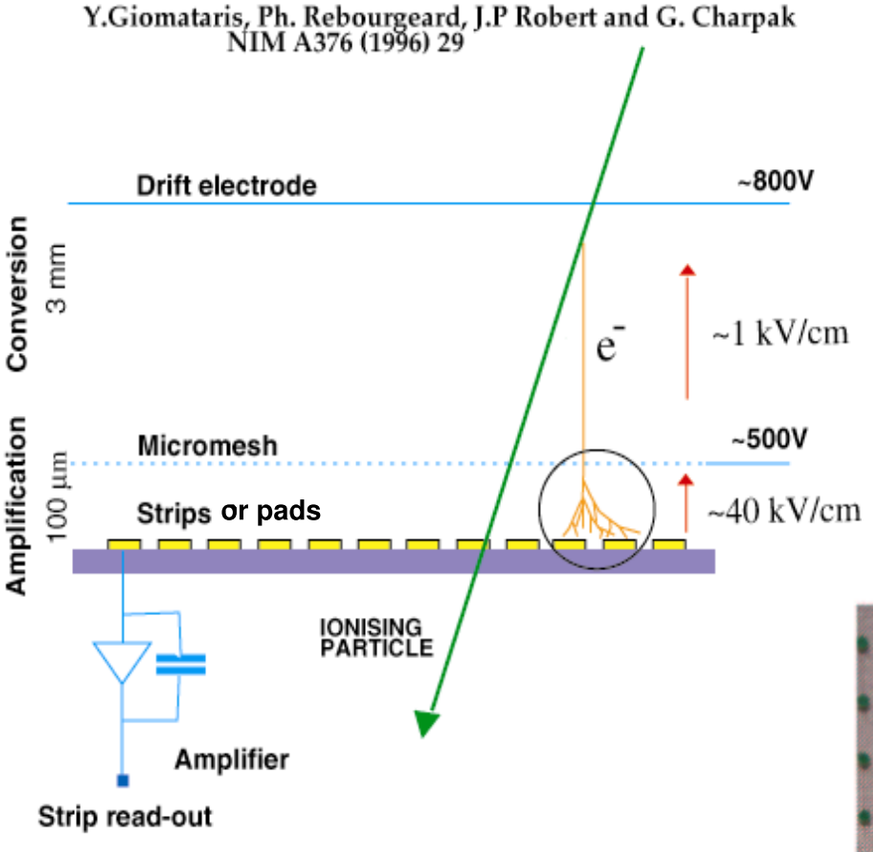
Fig. 1.5(a) Electric Field and (b) an avalanche across a GEM channel

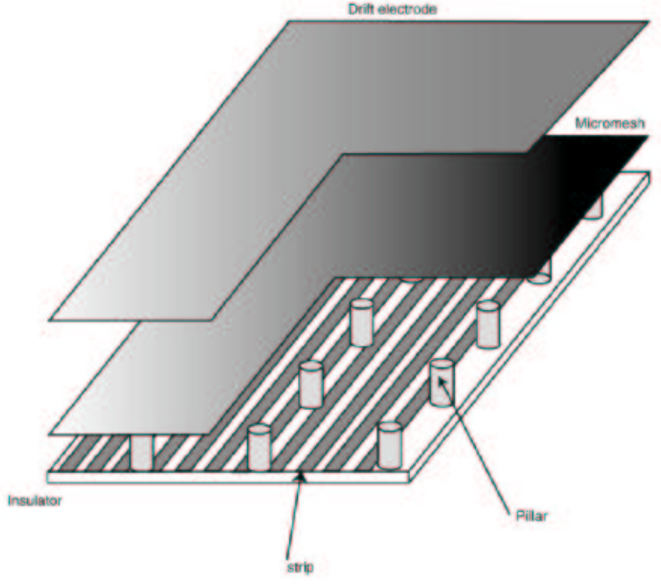
Coupled with a drift electrode above and a readout electrode below, it acts as a highly performing microparticle detector. The essential and advantageous feature of this detector is that amplification and detection are decoupled, and the readout is at zero potential. Permitting charge transfer to a second amplification device, this opens up the possibility of using a GEM in tandem with an MSGC or a second GEM.



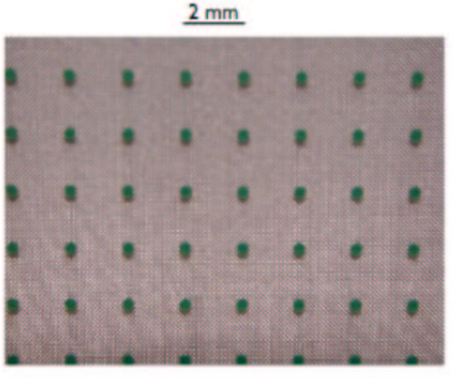
Digital Hadron Calorimetry

Micro mesh gaseous structure

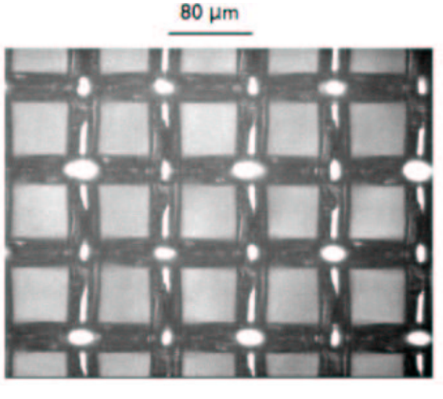




PILLARS



MICROMESH



(slide by Y.Karyotakis)

Testbeam Program - Studies

- **. technical studies**
  - : production debugging, quality control
  - : operation debugging
  - : calibration, monitoring
  - : . . .
- **. calorimeter characterization/studies**

: energy resolution	: response linearity
: position resolution	: response uniformity
: angular resolution	: particle identification
: shower development/profiles	: shower containment
: double particle separation	: saturation/leakage effects

CALICE-ECAL testbeam at DESY 2005

- **"30%" equipped Si/W prototype**

  : i.e. 14 W layers (10 at 1.4mm + 4 at 2.8mm) interleaved with 18 $\times$ 12 matrix of active Si cells, 1 $\times$ 1 cm^2 each,
  total: 3024 channels

  : first testbeam with electrons during Jan/Feb05

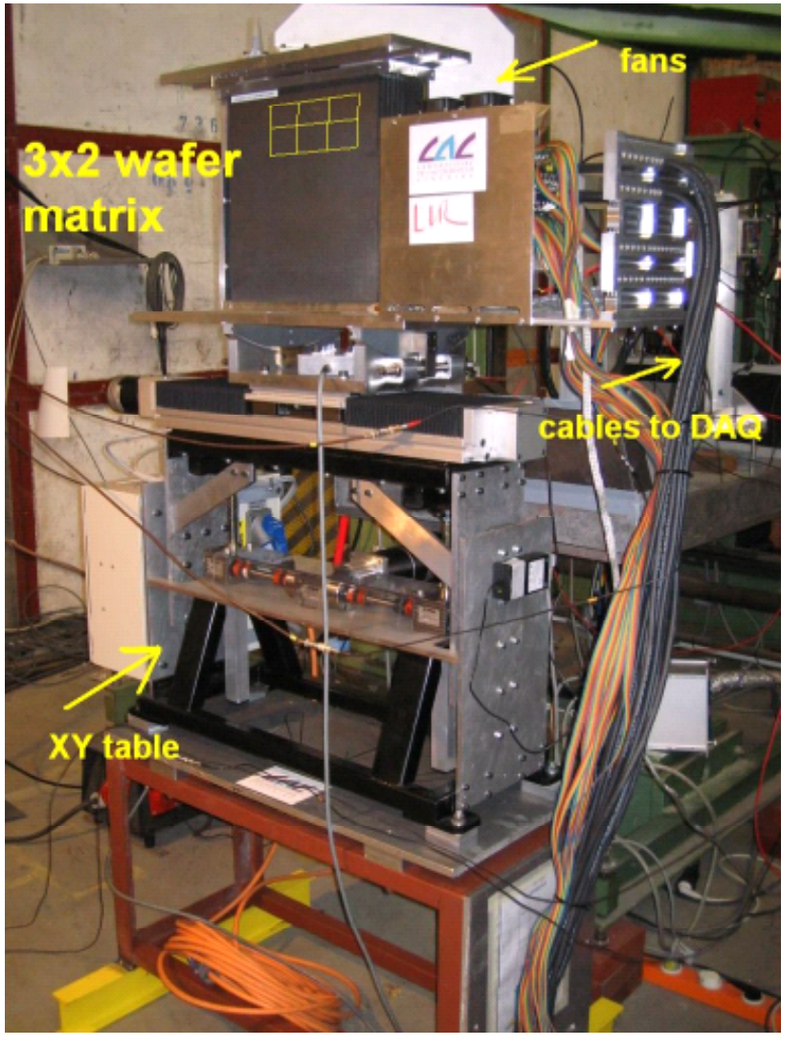
- **in summary (configurations: position $\times$ energy $\times$ angle)**

  : position scan (center - edge - corner of wafers)
  energy scan (mainly 1, 2, 3 GeV, some runs at 4, 5, 6 GeV)
  angle scan (0°, 10°, 20°, 30°)

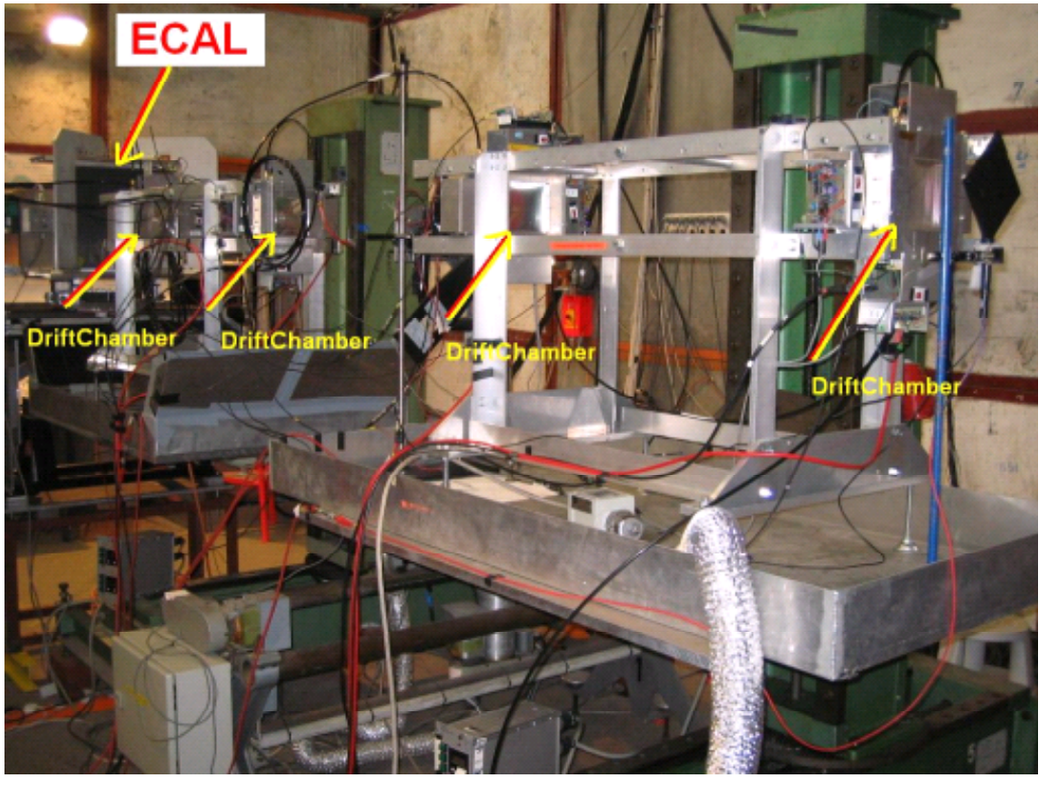
  : total: $\sim$ 25 Mevents

CALICE-ECAL testbeam at DESY

ECAL

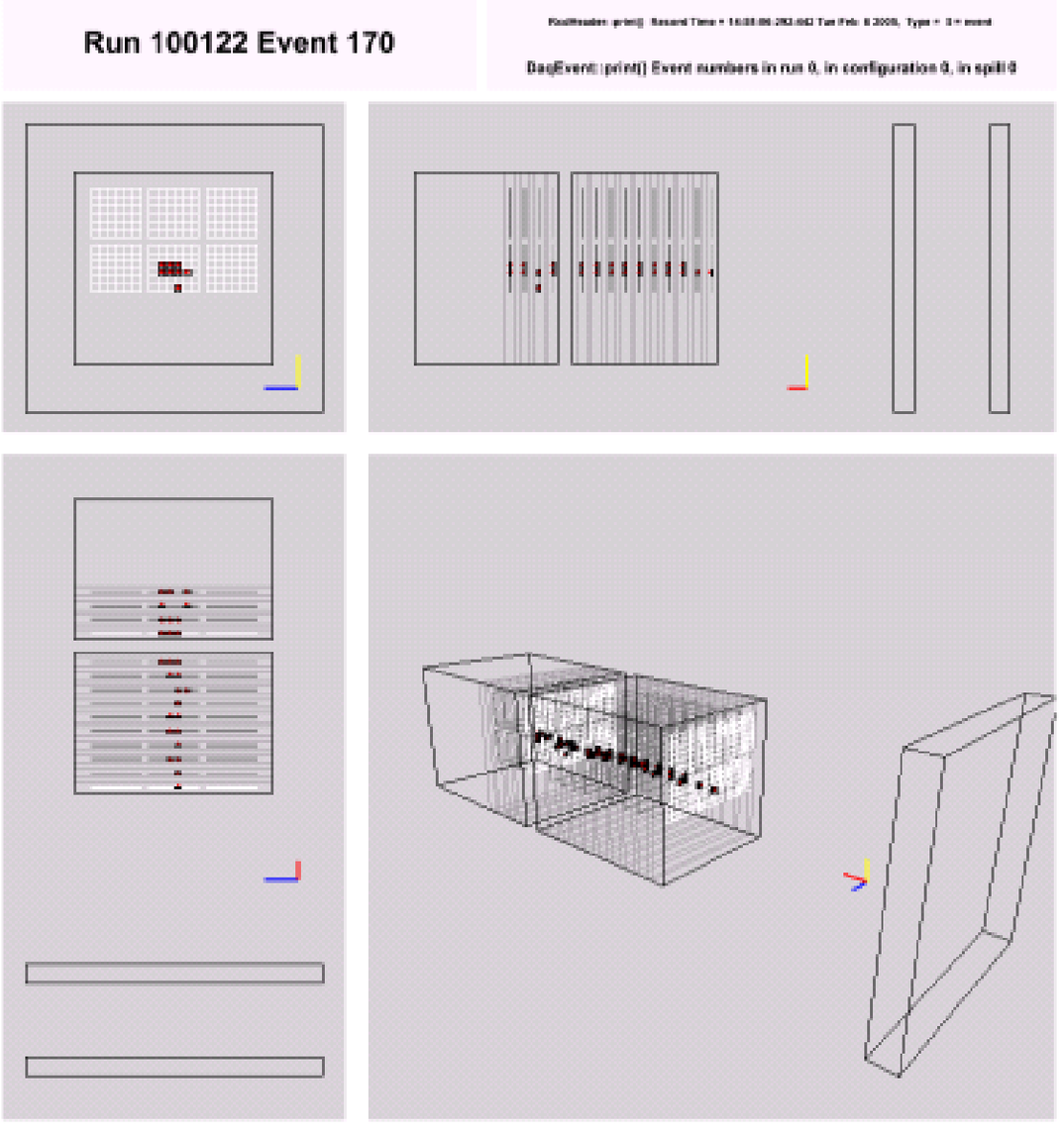


layout at DESY T21



DriftChambers and installation courtesy of Tsukuba Univ. and Kobe Univ.

"Tracking Calorimetry"

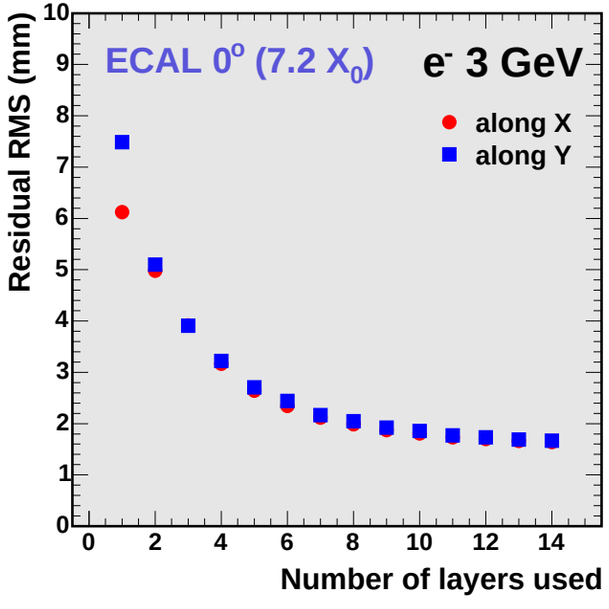


(not to scale)

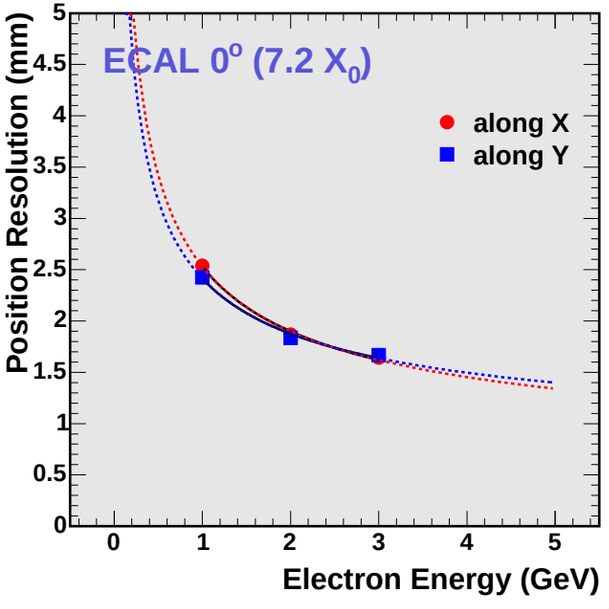
e^- 1 GeV

cell threshold = 0.5 mip

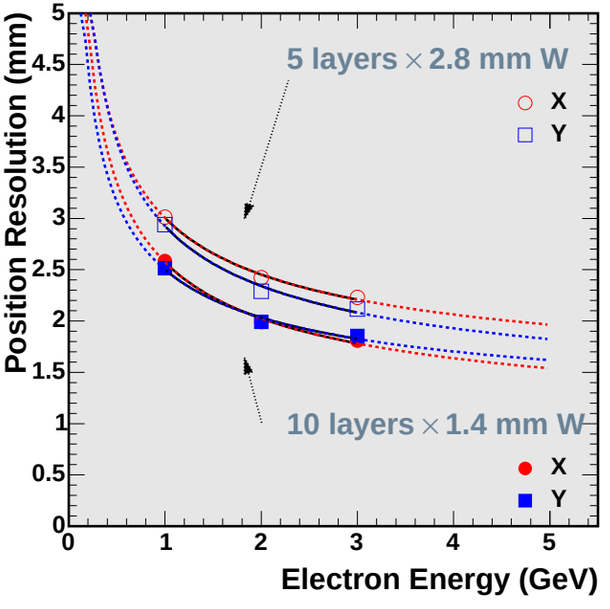
Position resolution



vs layers

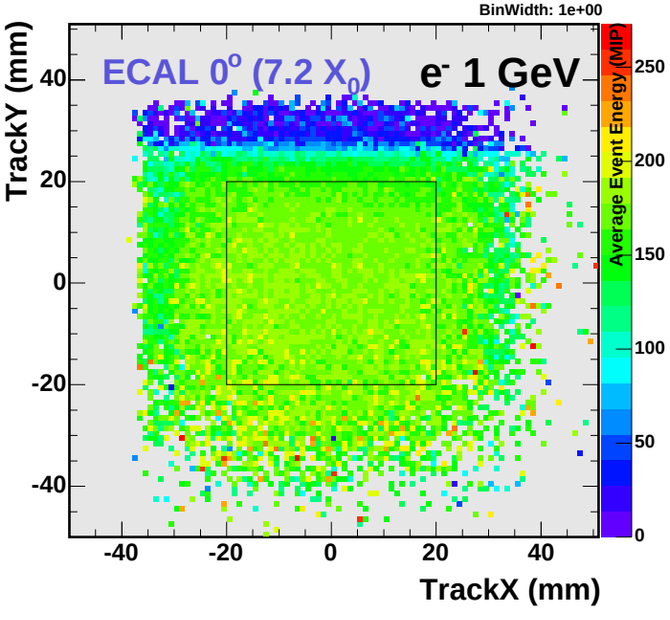


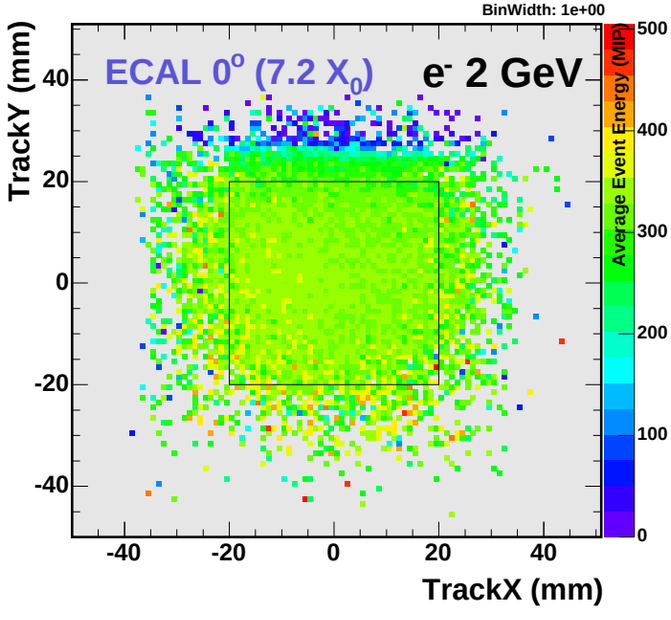
vs energy

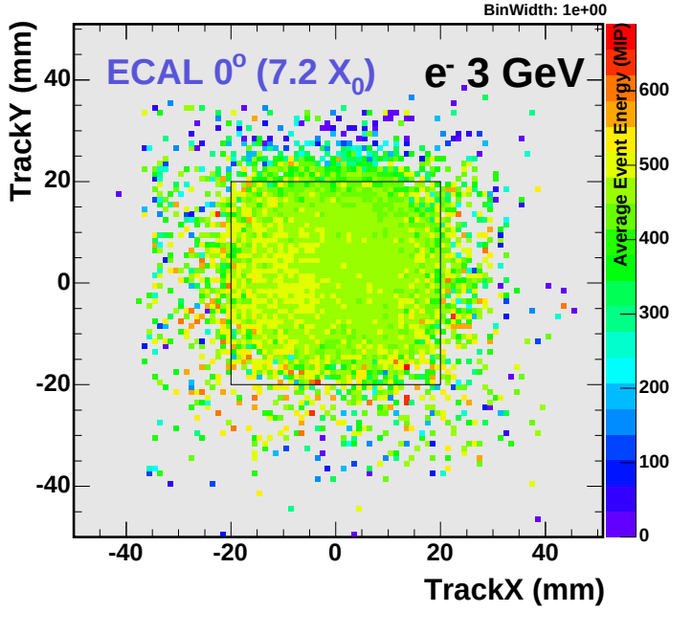


vs sampling

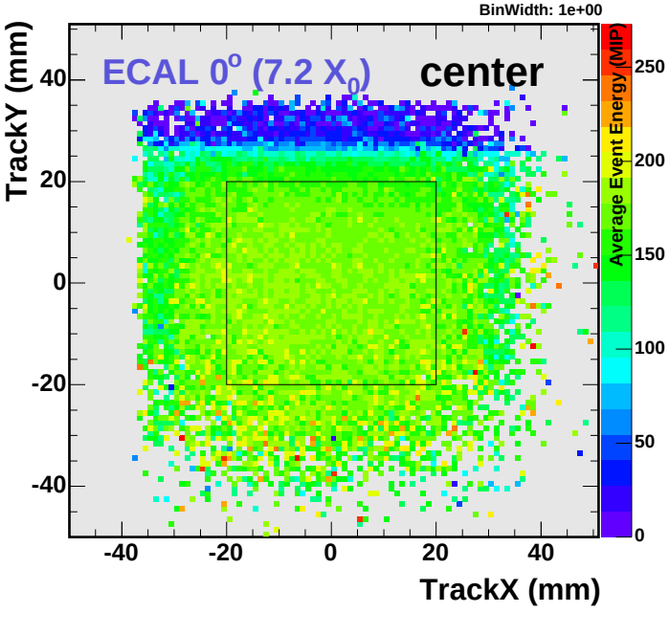
Response map - center of wafer

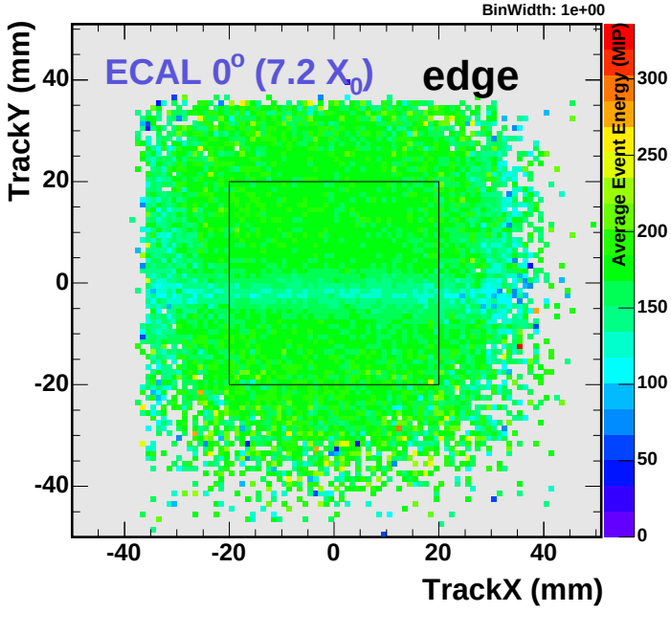


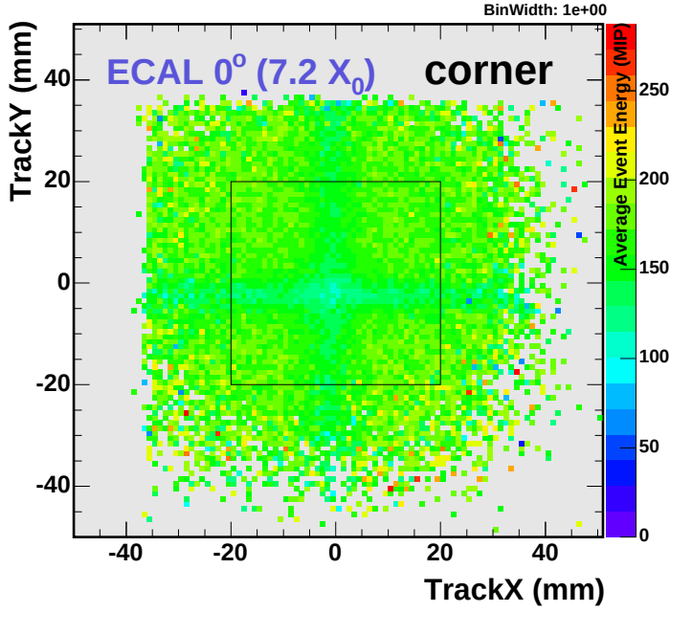




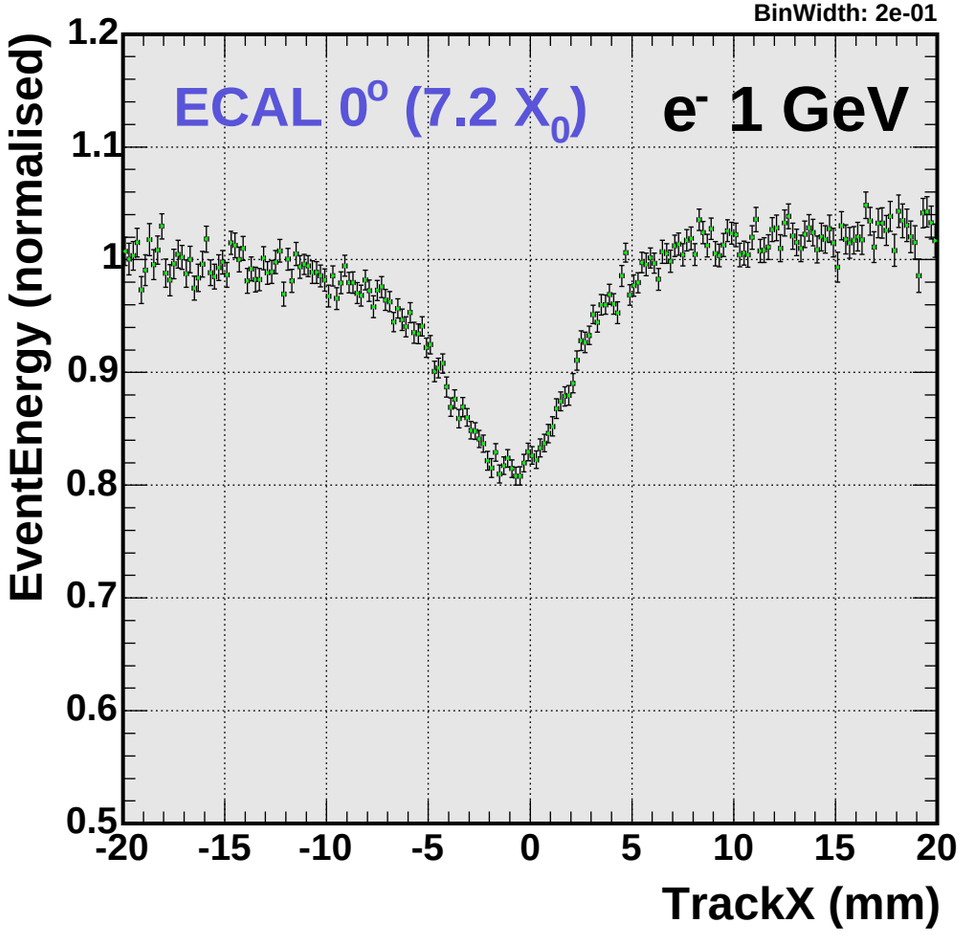
Response map - center/edge/corner of wafer

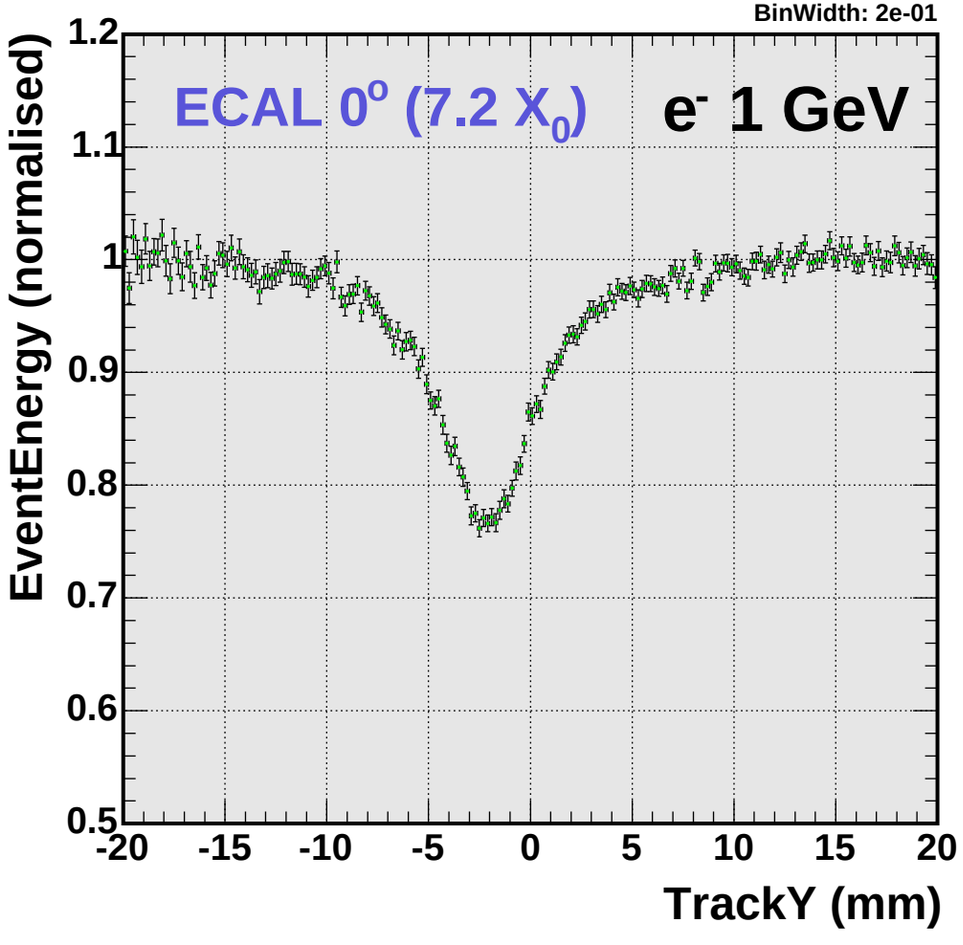






Position scan along wafer borders

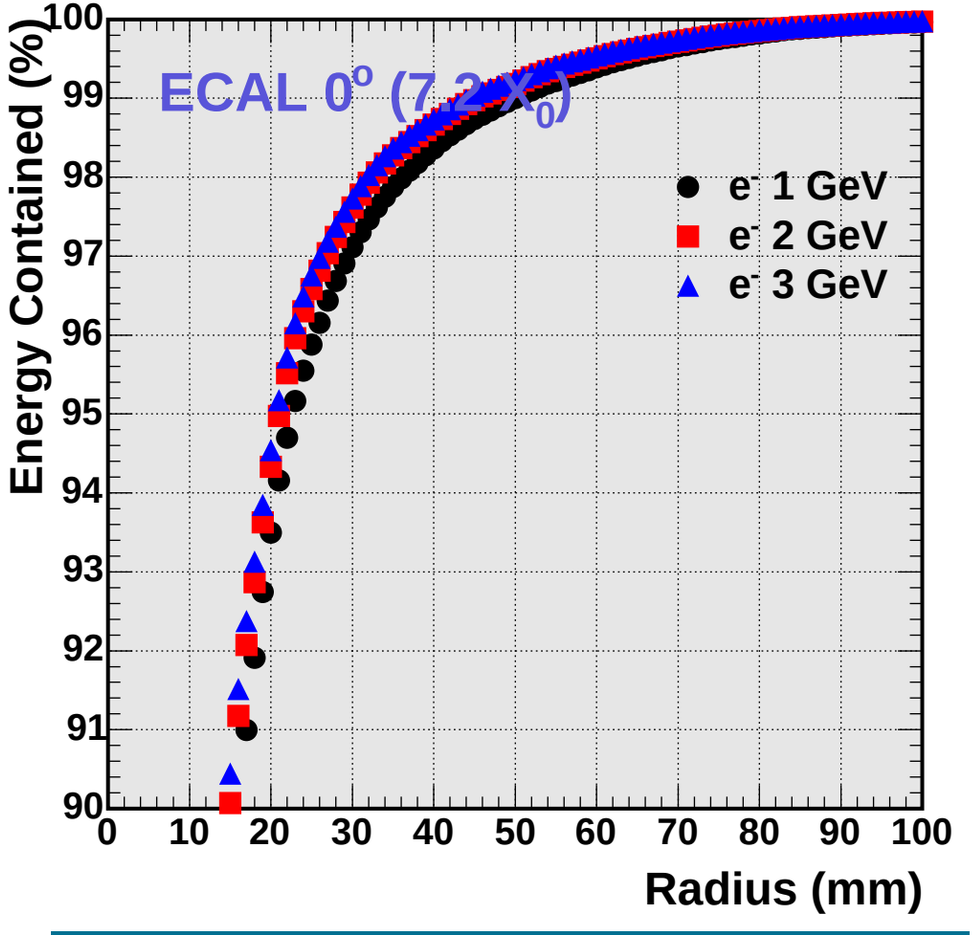


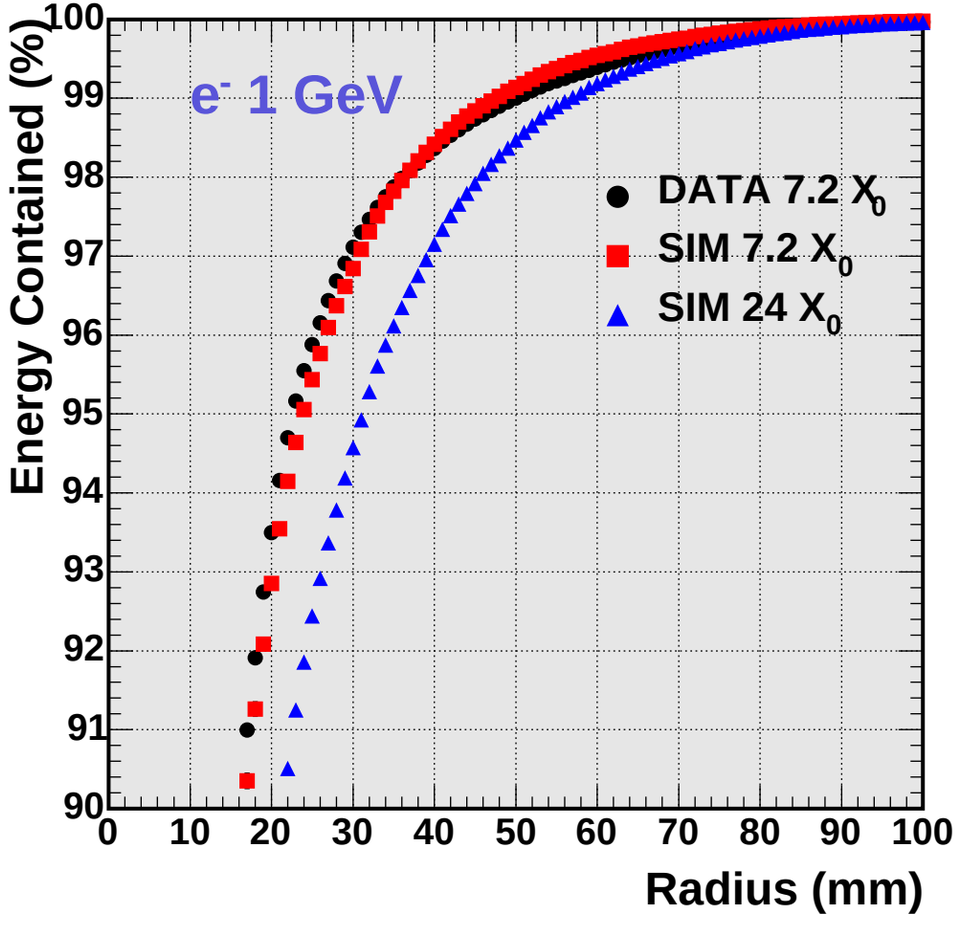


- alternate layers staggered along X (by 2.5 mm)
- dip is shallower and wider

- layers not staggered along Y
- dip is deeper and narrower

Transverse containment (Moliere radius)





REMINDER: **for an infinitely long and wide calorimeter**

shower contained at 90% within radius $\sim 1\ R_M$
95% $\sim 2\ R_M$
99% $\sim 3.5\ R_M$

(for solid W, $R_M \simeq$ 10 mm)

- ▷ **data-simulation comparison**
- ▷ **results expected for the 24 X_0 prototype**

Testbeam Program 2006

- **DESY, 22 May - 31 May**

  : ECAL testbeam with electrons at 1-6 GeV

- **CERN, 28 Jul - 9 Aug**

  : ECAL testbeam with electrons at higher energy

  : HCAL, TCMT commissioning

- **CERN, 24 Aug - 3 Sep**

  : mainly HCAL technical run with electrons/pions

- **CERN, 12 Oct - 24 Oct**

  : combined (ECAL+HCAL+TCMT) physics run with electrons/pions

ECAL testbeam at DESY, May 2006

- **Si/W prototype**

  : 24 layers (10 at 1.4mm W + 10 at 2.8mm + 4 at 4.2mm) equipped with 18×12 matrix of active Si cells, **cellsize: 1×1 cm^2**,
  total: **5184 channels**

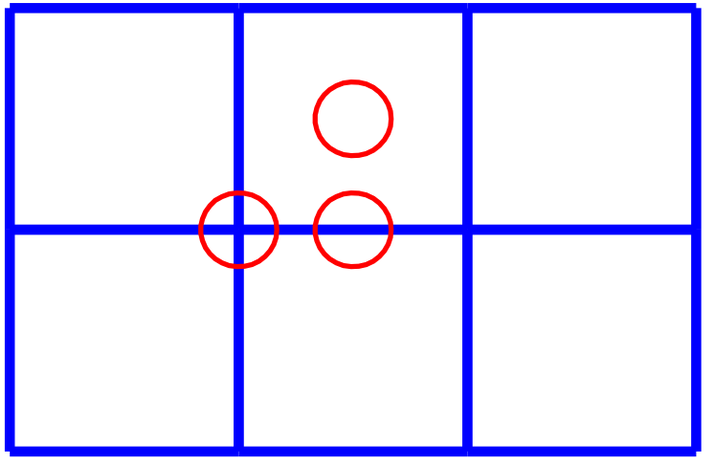
- **in summary (configurations: position $\times$ energy $\times$ angle)**

  : testbeam with electrons

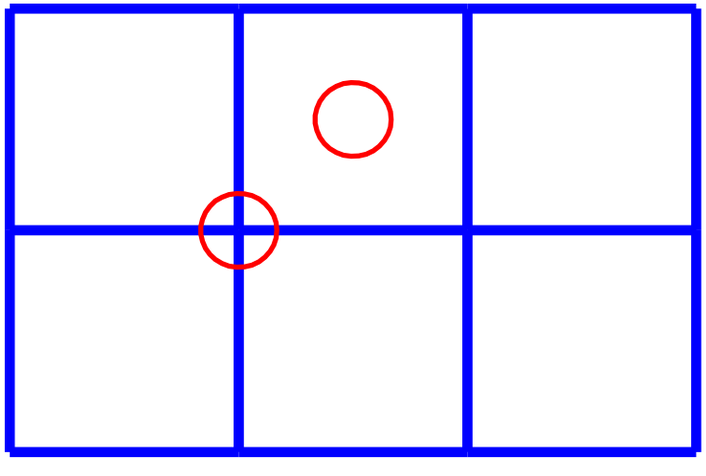
  : position scan (center - edge - corner of wafers)
  energy scan (1, 1.5, 2, 3, 4, 5, 6 GeV)
  angle scan (0°, 10°, 20°, 30°, 45°)

  : **total: $\sim$ 8 Mevents**

Testbeam at DESY with electrons

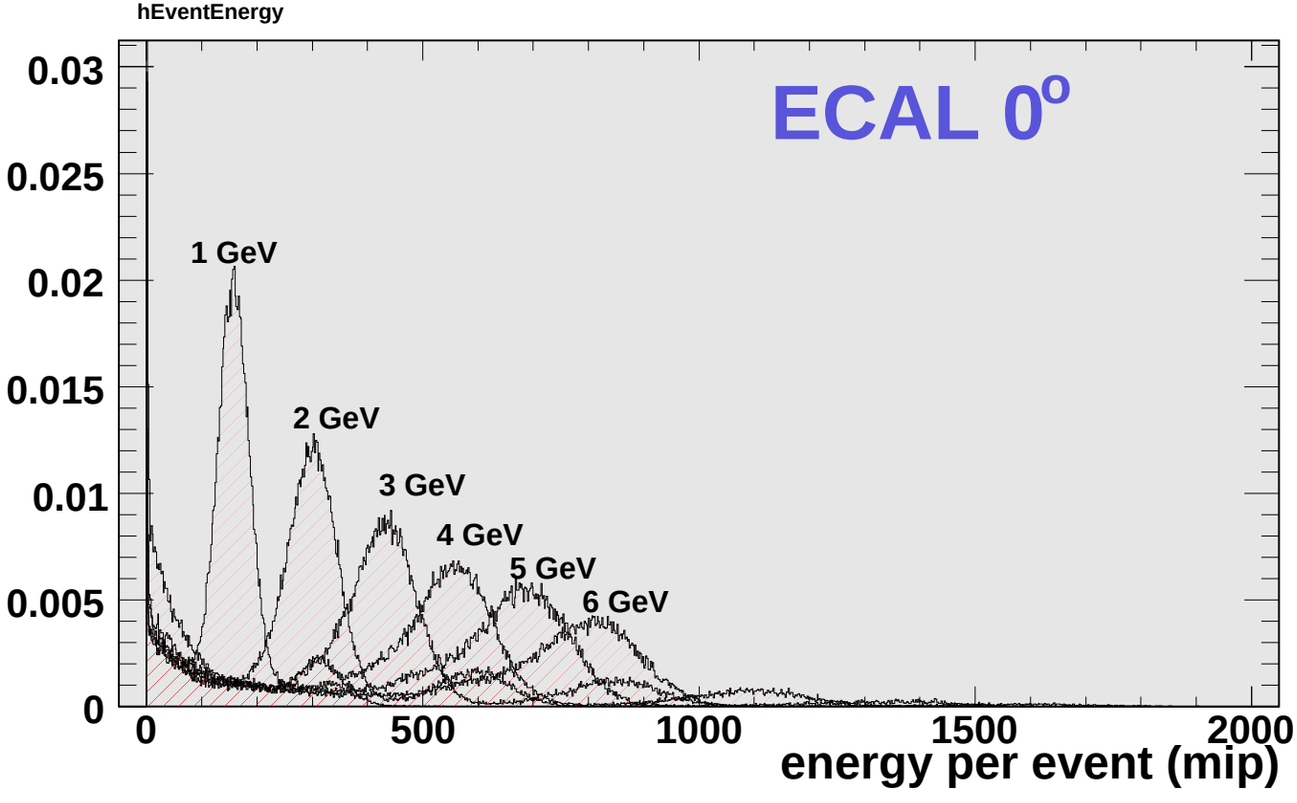


- ECAL at 0°
  three position points
- energy scan (1, 1.5, 2, 3, 4, 5, 6 GeV)
- 100k events per sample



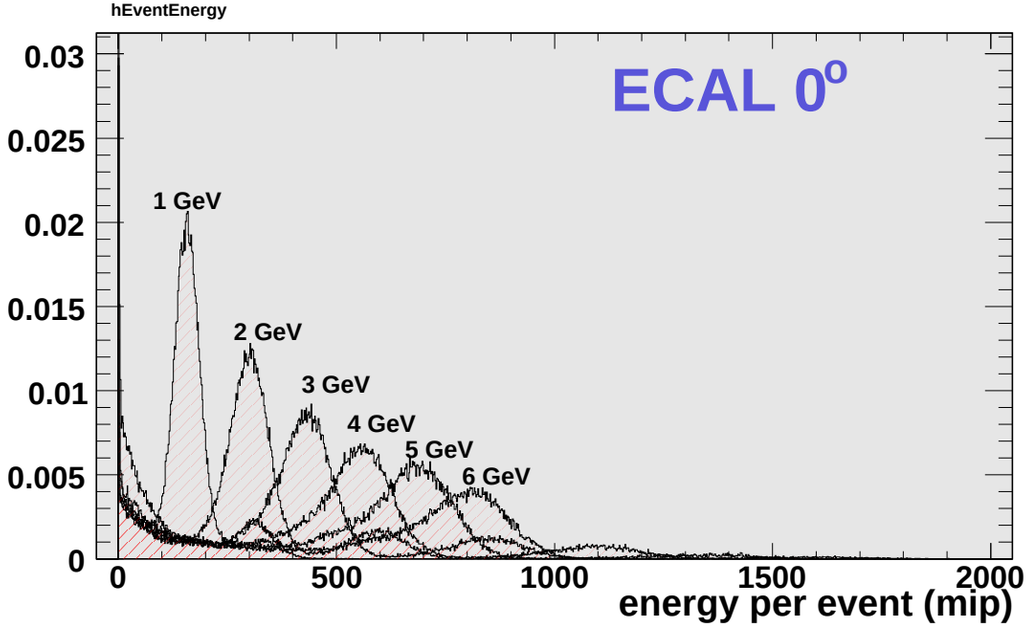
- angle scan (10°, 20°, 30°, 45°)
  two position points
- energy scan (1, 1.5, 2, 3, 4, 5, 6 GeV)
- 100k events per sample

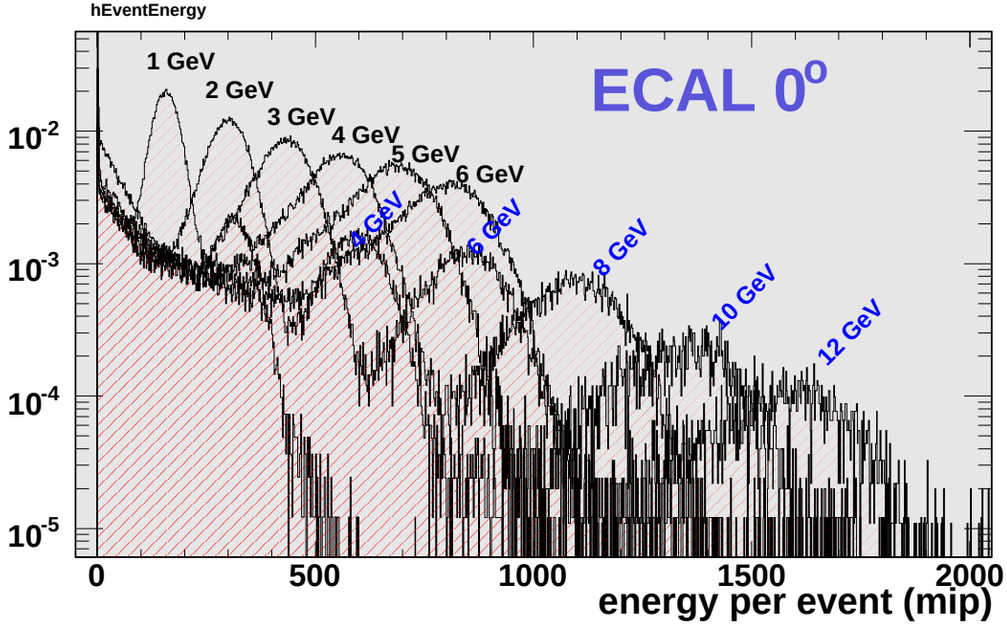
Response to electrons



(raw data, no cleaning, no event selection)

Response to electrons



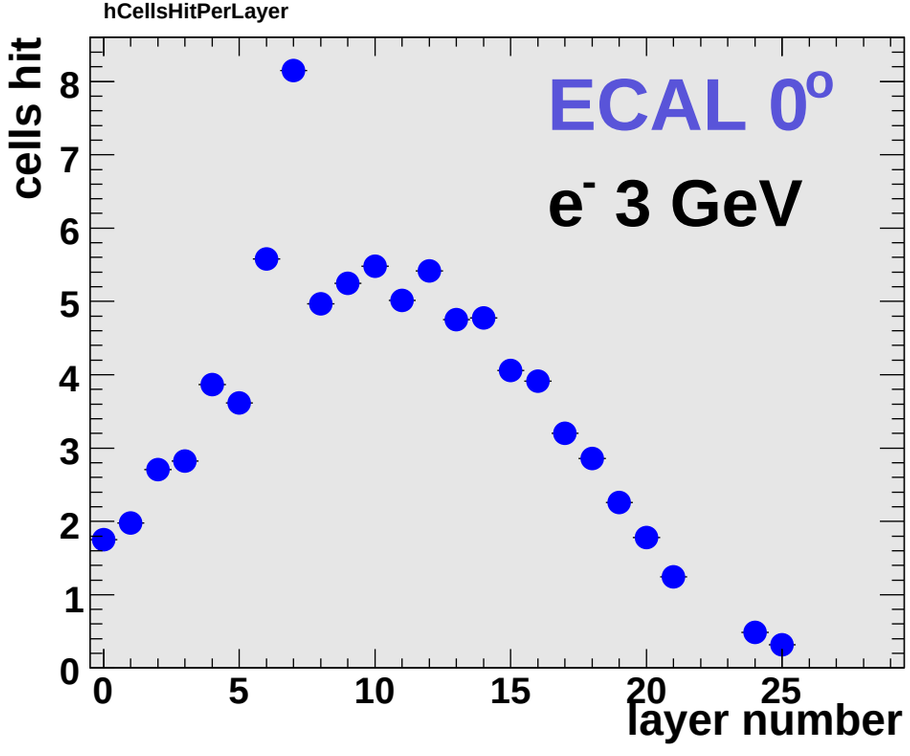


- a lot of double-particle events observed
- useful for clustering and double-particle separation studies

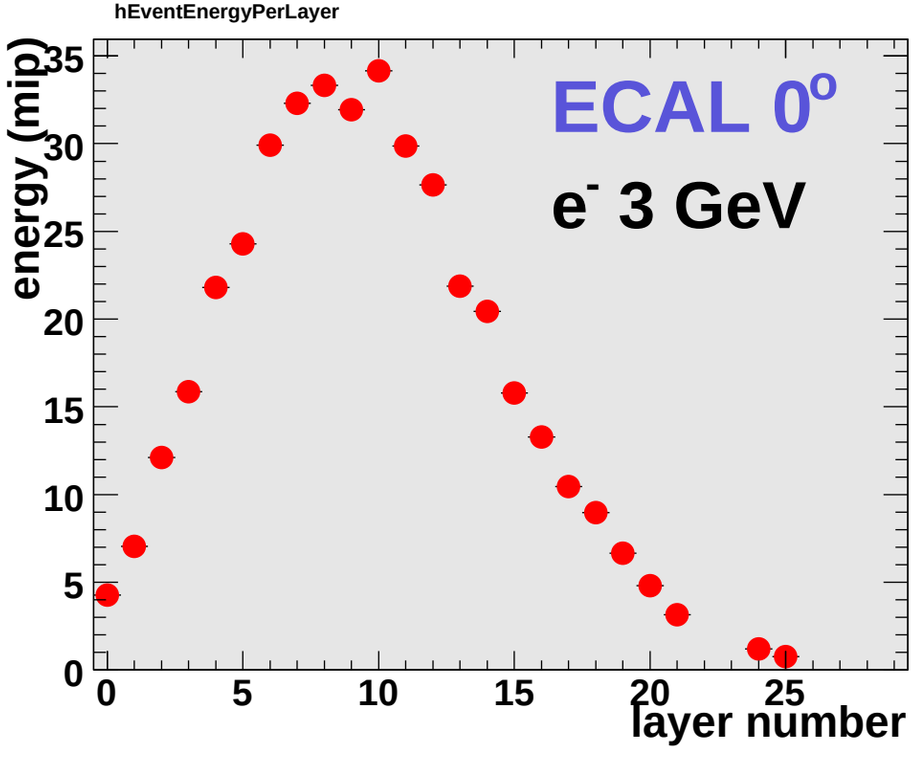
(raw data, no cleaning, no event selection)

Shower longitudinal profile

Hits per layer



E per layer



- showers are well contained
- some layers show high noise

(raw data, no cleaning, no event selection)

ECAL testbeam at CERN, Aug 2006

- **Si/W prototype**

  : 30 layers (10 at 1.4mm W + 10 at 2.8mm + 10 at 4.2mm) equipped with 18×12 matrix of active Si cells, **cellsize: 1×1 cm^2**,
  total: **6480 channels**

- **run plan**

  : ECAL testbeam with electrons at higher energy

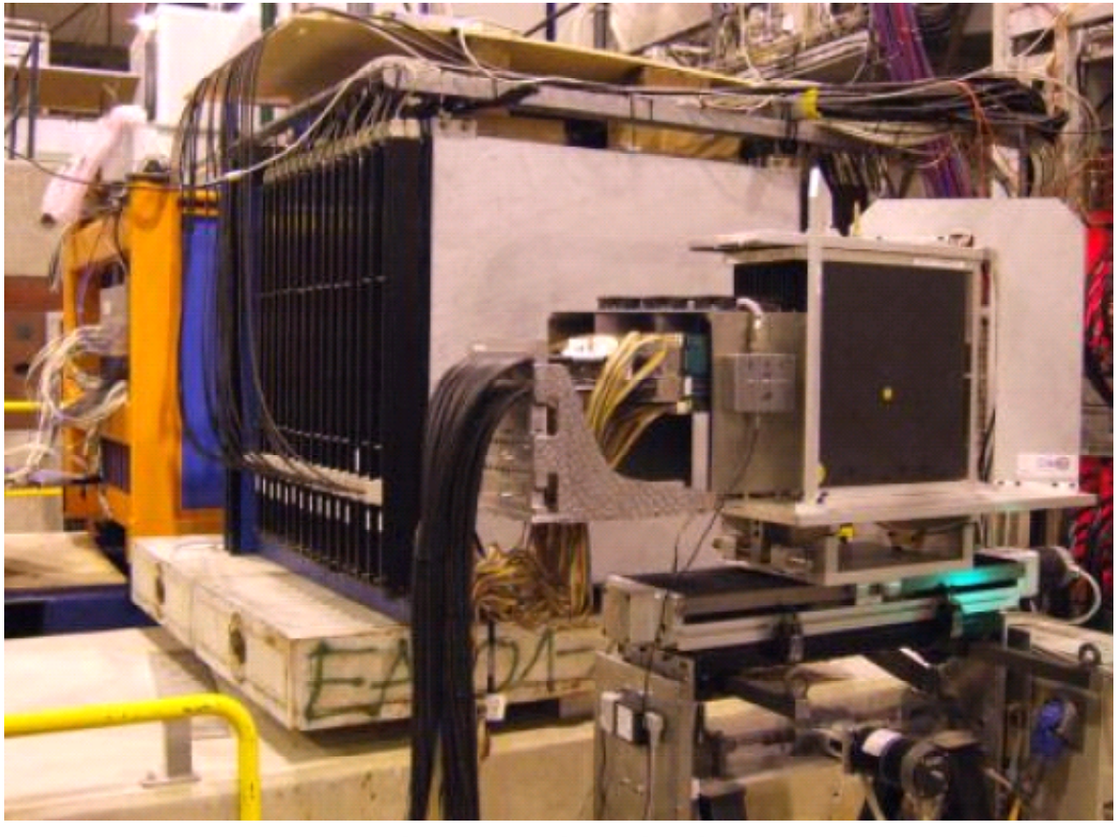
  : HCAL+TCMT commissioning

  : beam tuning

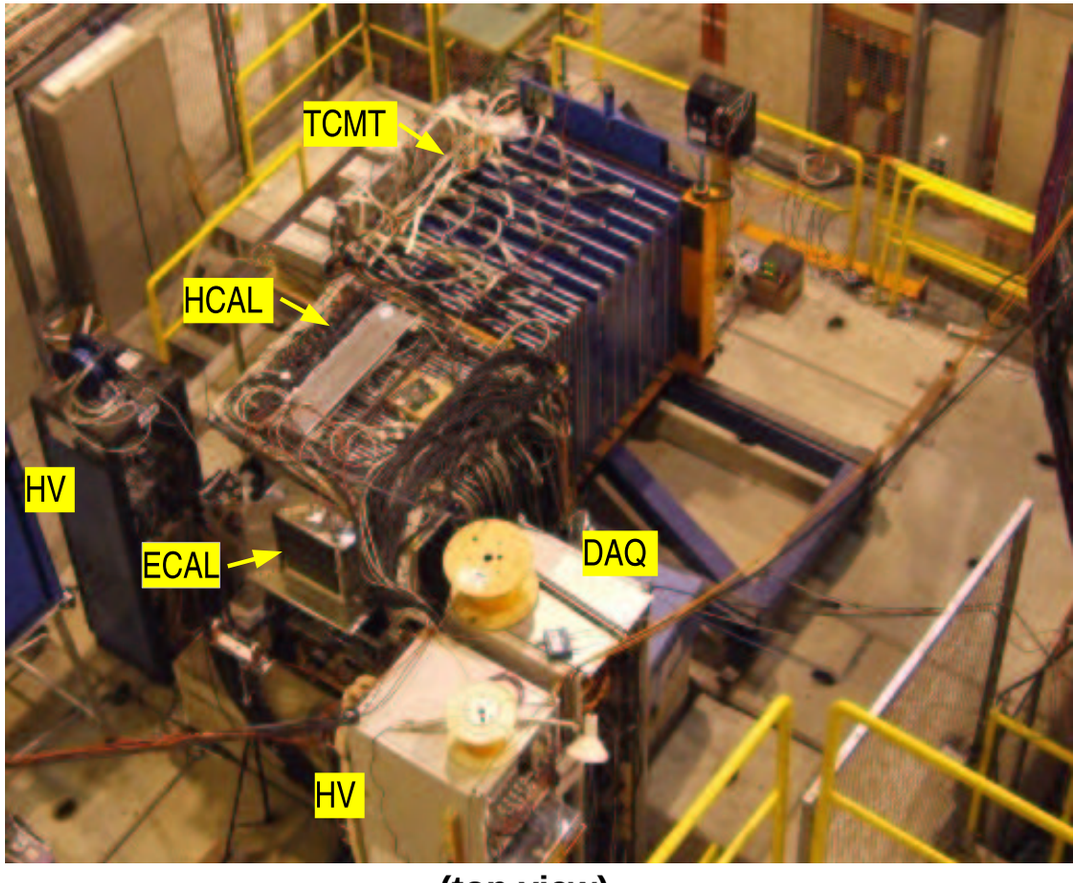
- **C A N C E L L E D**

  : CERN suffered a severe power failure, all testbeams cancelled

CALICE Testbeam at CERN 2006



(perspective view)



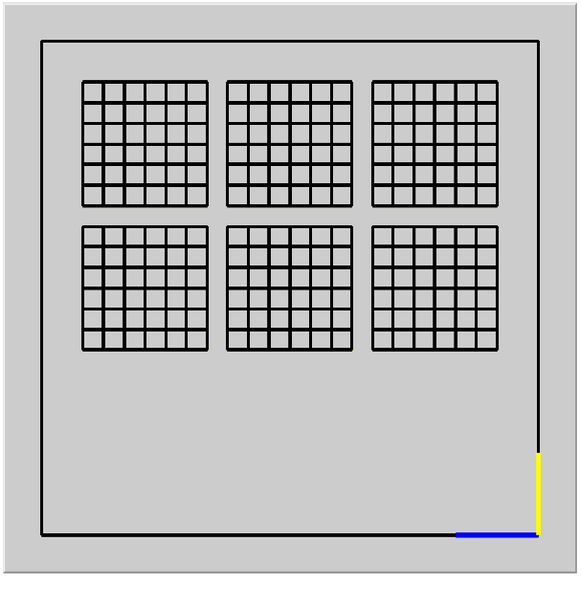
(top view)

Transverse granularity

ECAL 18×18 cm^2

Si cells of 1×1 cm^2

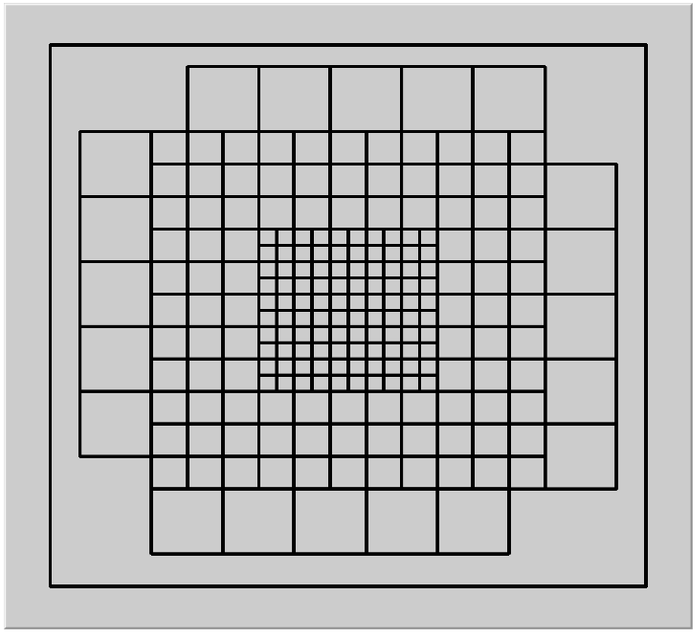
(216 cells per layer)



HCAL 100×100 cm^2

scint.tiles of 3×3, 6×6, 12×12 cm^2

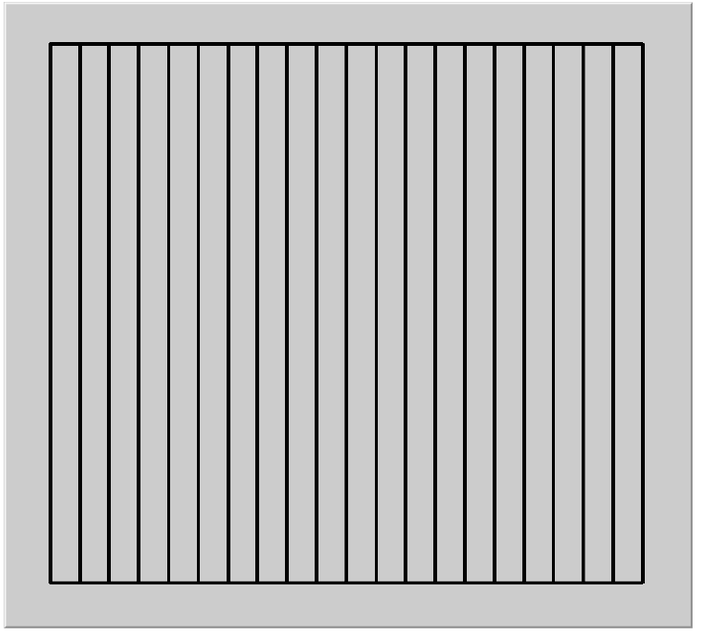
(216 tiles per layer)



TCMT 100×100 cm^2

scint.strips X or Y of 5×100 cm^2

(20 strips per layer)



Tail Catcher - Muon Tracker

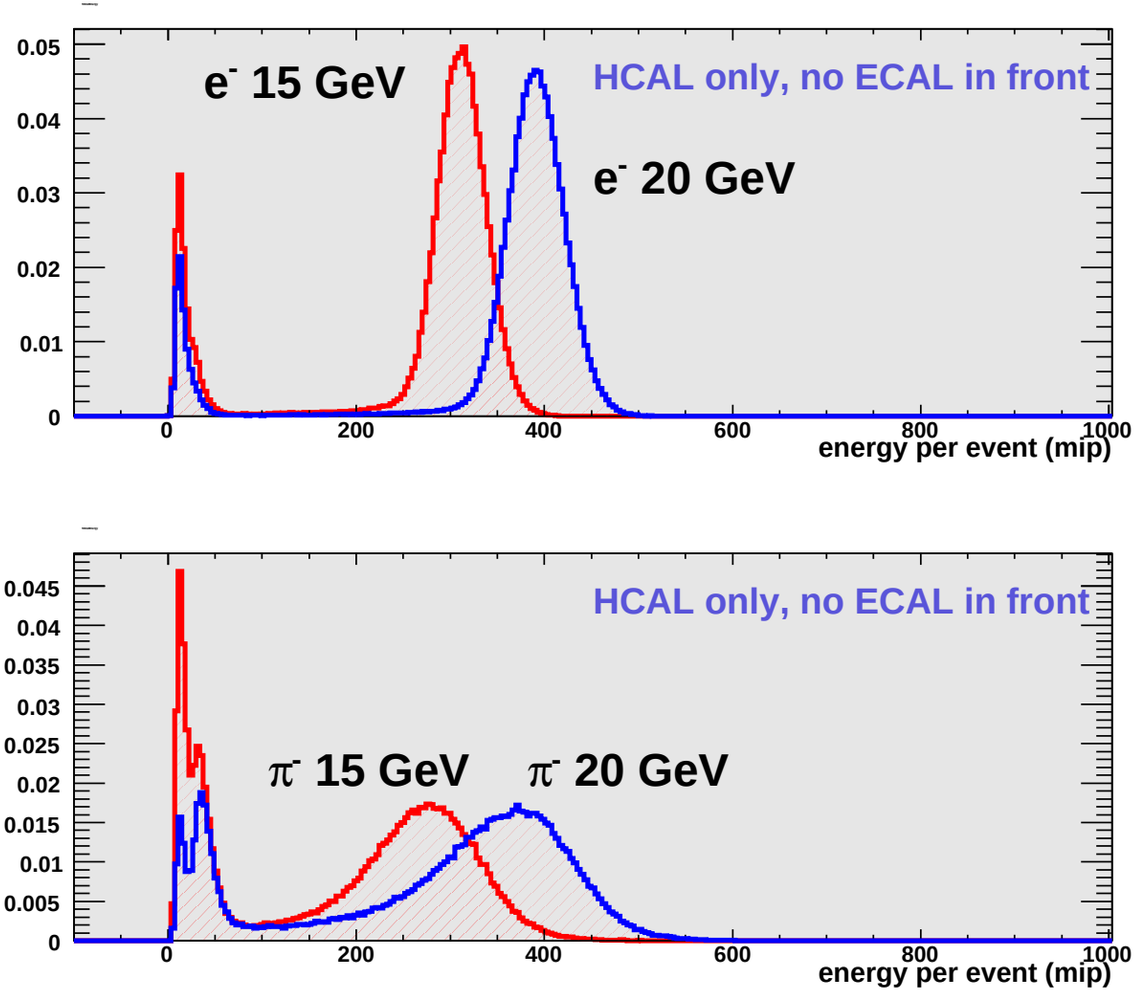
HCAL testbeam at CERN, Aug 2006

- **Particle ID**
  - : Cherenkov counter, 1 bit signal
- **Tracker**
  - : 3 XY chambers
- **Calorimeters**
  - : ECAL: 30 layers, 6480 channels
  - : HCAL: 15 modules, 3240 channels
  - : TCMT: 8 modules, 160 channels

HCAL testbeam at CERN, Aug 2006

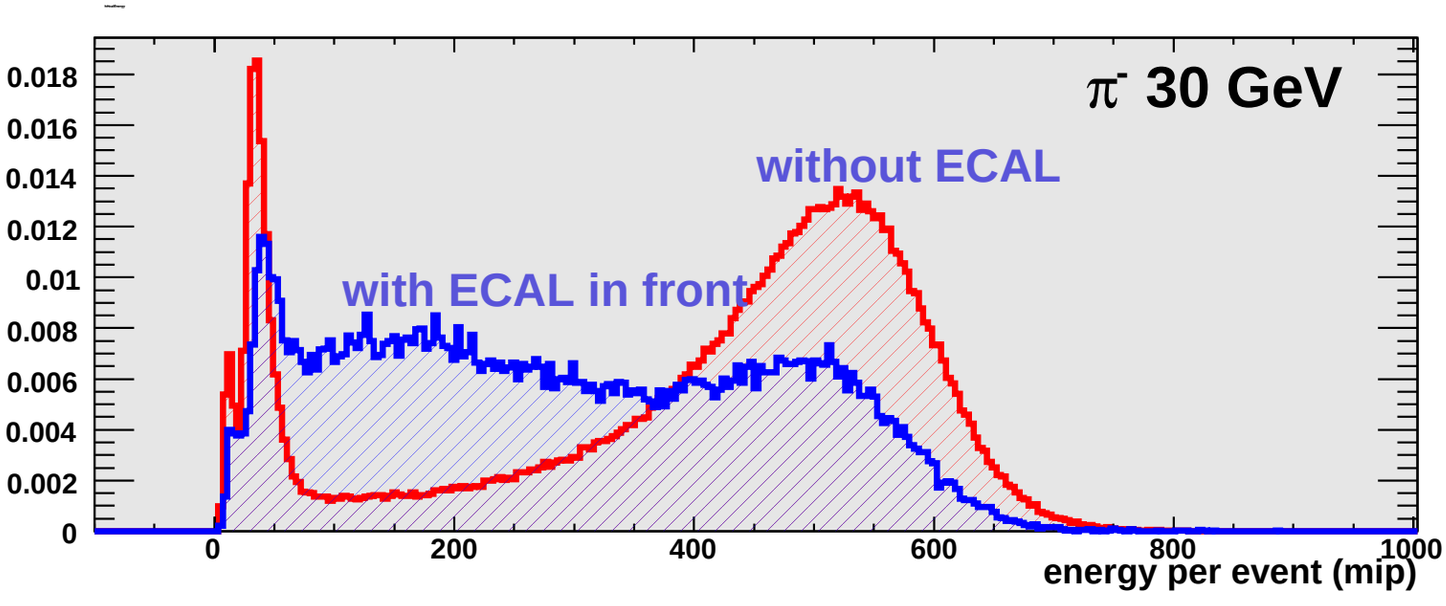
- **HCAL alone, no ECAL in front**
  - : electron beam, energy scan (6, 10, 15, 20, 30, 40, 45 GeV)
  - : pion beam, energy scan (6, 10, 15, 20, 30, 40, 50, 60, 80 GeV)
- **ECAL+HCAL**
  - : pion beam, energy scan (30, 40, 50, 60, 80 GeV)
- **ECAL**
  - : electron beam, energy scan (10, 15, 20, 30, 40, 45 GeV)
    angle scan (0°, 30°, 45°)
- **samples of 500-600k events collected**

HCAL e/π ratio



(raw data, no cleaning, no event selection)

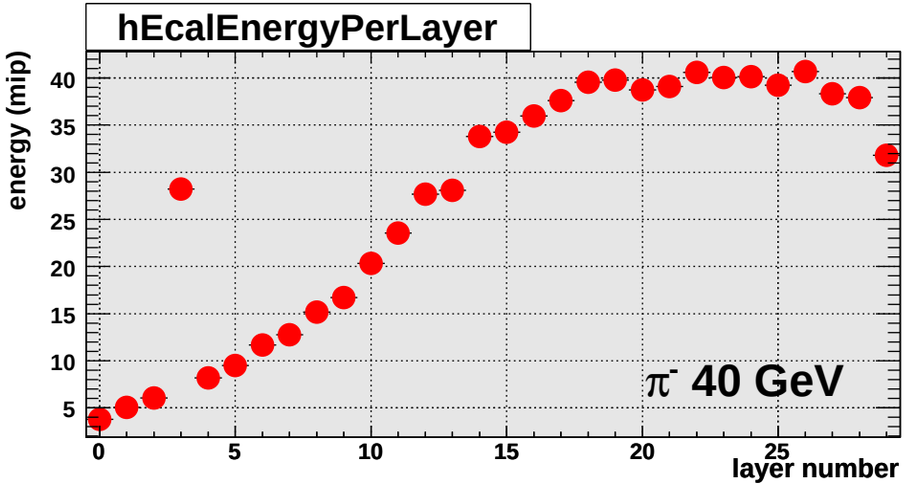
HCAL response with/without ECAL in front

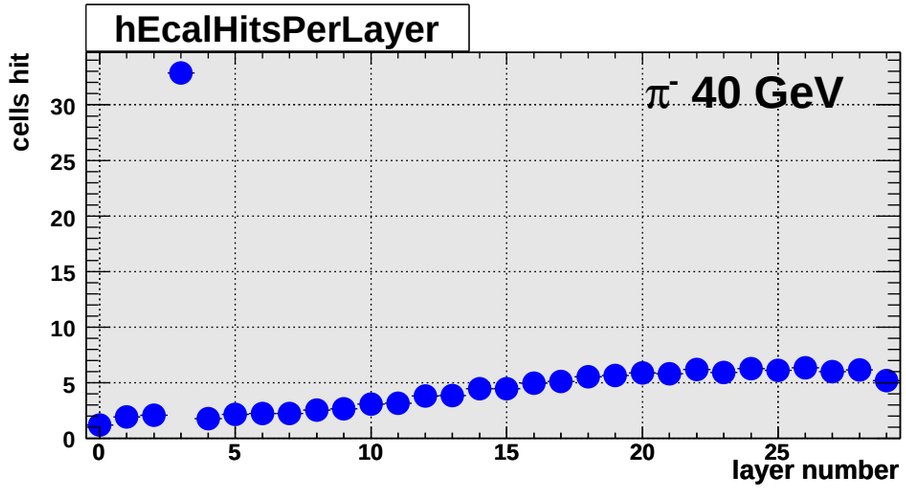


(raw data, no cleaning, no event selection)

Shower longitudinal profile

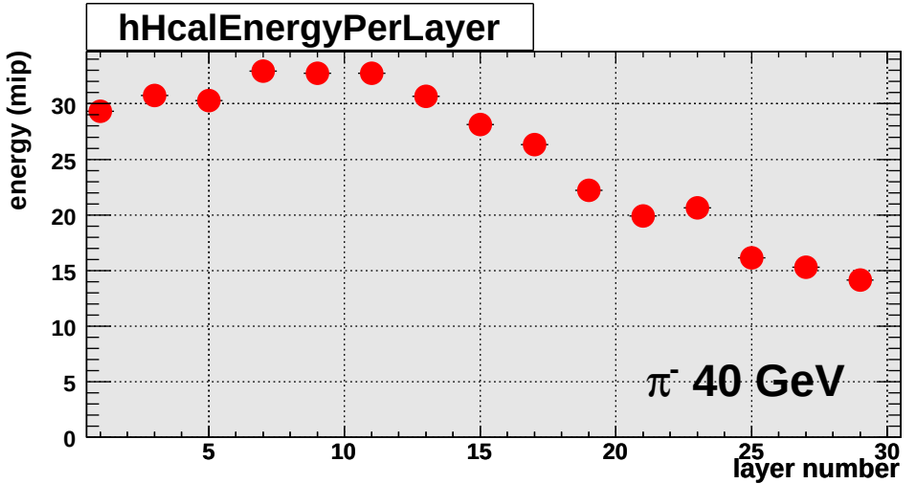
ECAL

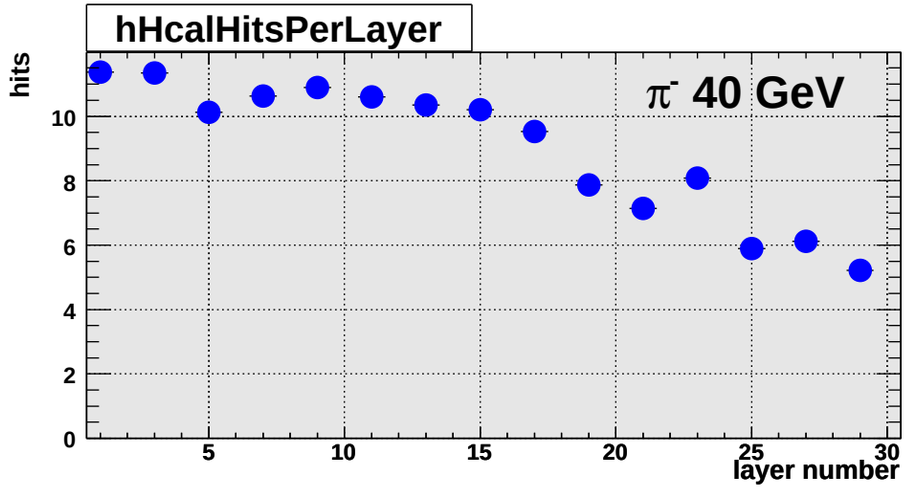




▷ some layers with high noise

HCAL

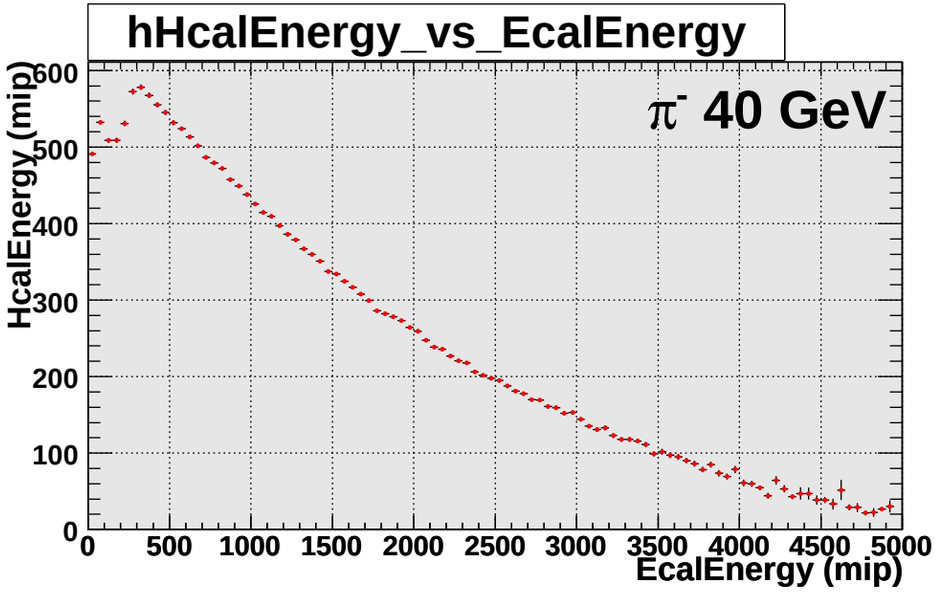


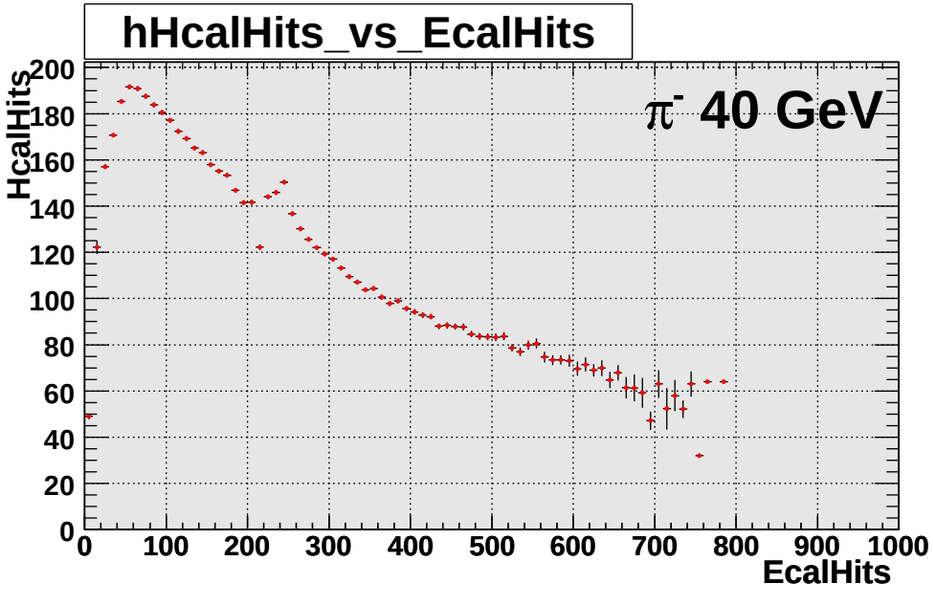


▷ only odd layers equipped and readout

(raw data, no cleaning, no event selection)

ECAL vs HCAL response





▷ **as expected strong anti-correlation observed**

(raw data, no cleaning, no event selection)

Combined testbeam at CERN, Oct 2006

- **Particle ID**
  - : Cherenkov counter, 1 bit signal
- **Tracker**
  - : 3 XY chambers
- **Calorimeters**
  - : **ECAL: 30 layers, 6480 channels**
  - : **HCAL: 23 modules, 4968 channels**
  - : **TCMT: completed, 16 modules, 320 channels**

Combined testbeam at CERN, Oct 2006

- **ECAL+HCAL+TCMT**

  : pion beam, energy scan (6, 10, 15, 20, 30, 40, 50, 80 GeV)
  samples of 500k events

- **ECAL**

  : positron beam, energy scan (10, 16, 15, 18, 20, 30, 50 GeV)
  samples of 300k events

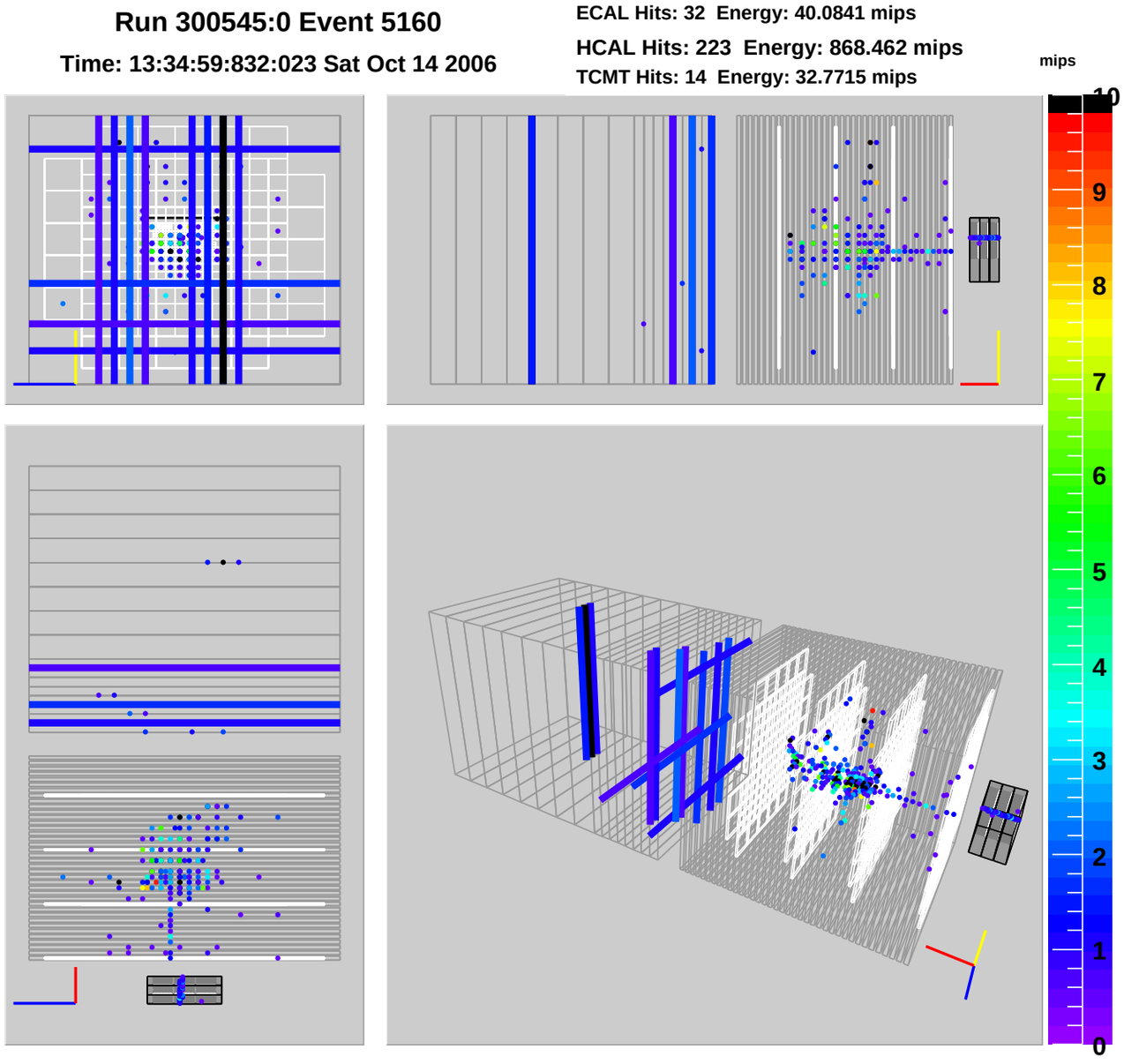
- **HCAL alone, no ECAL in front**

  : positron beam, energy scan (10, 15, 20, 30, 50 GeV)
  samples of 600k events

- **parasitic run**

  : 25M muon events collected

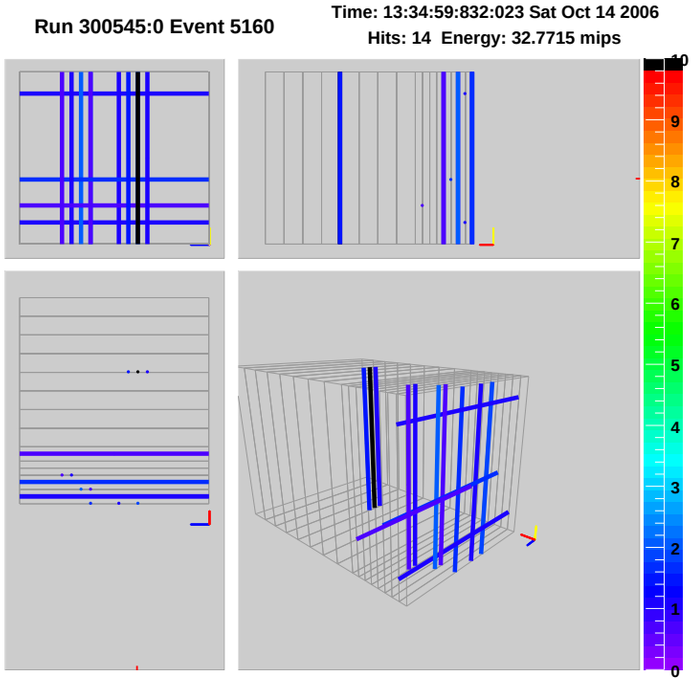
CALICE testbeam at CERN



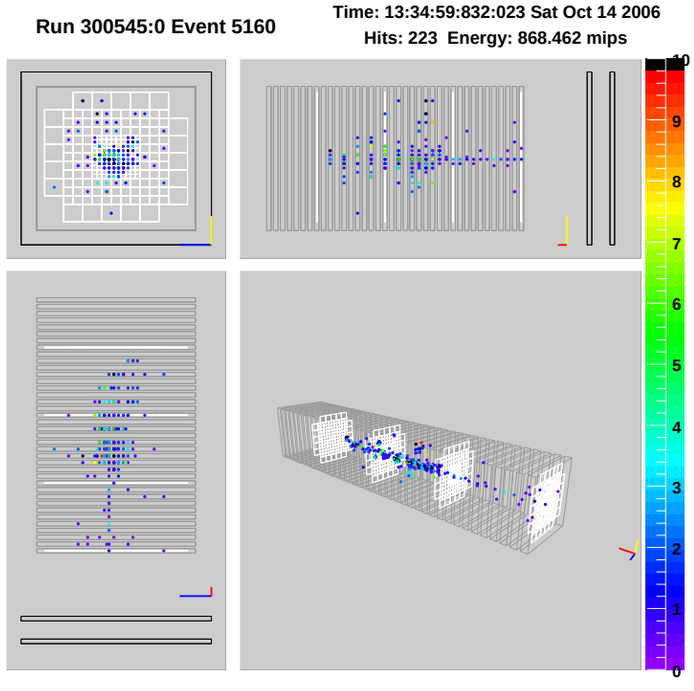
π^- 30 GeV

ECAL threshold = 0.5 mip
HCAL threshold = 0.5 mip
TCMT threshold = 0.7 mip

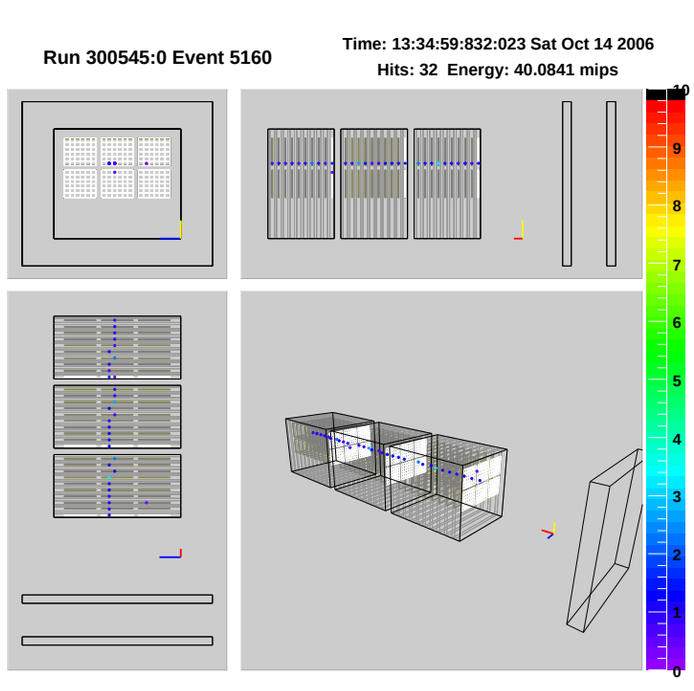
CALICE testbeam at CERN



TCMT



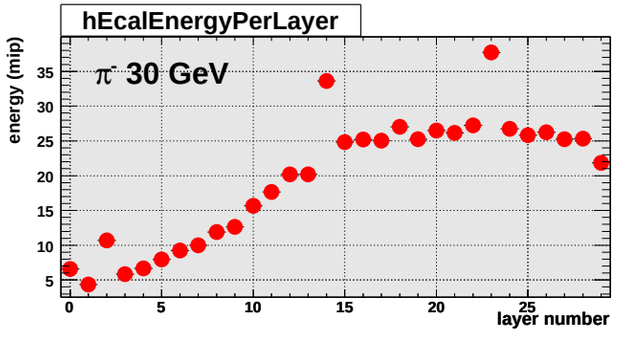
HCAL

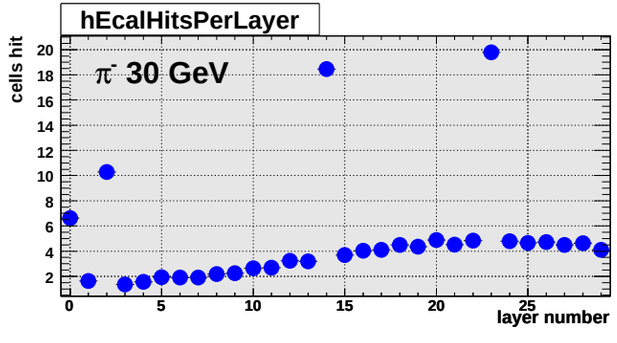


ECAL

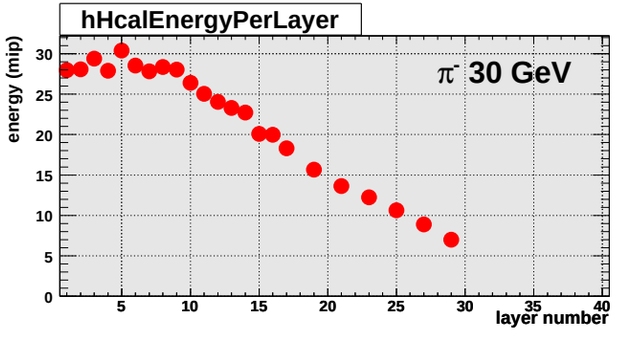
Shower longitudinal profile

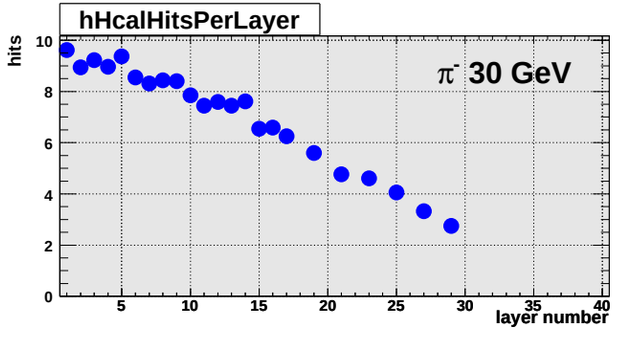
ECAL



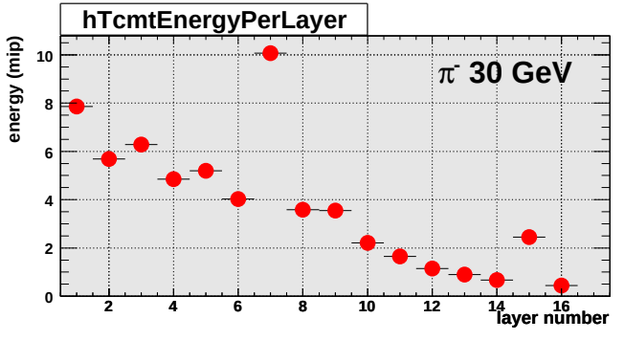


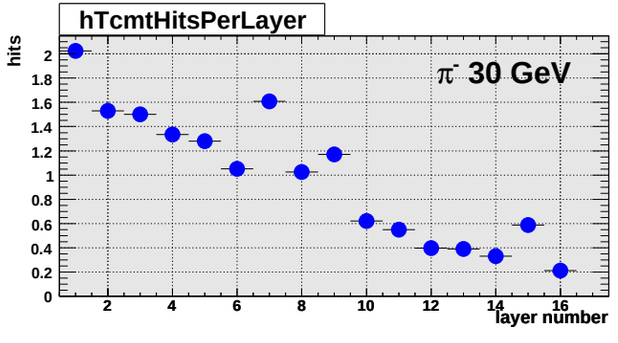
HCAL





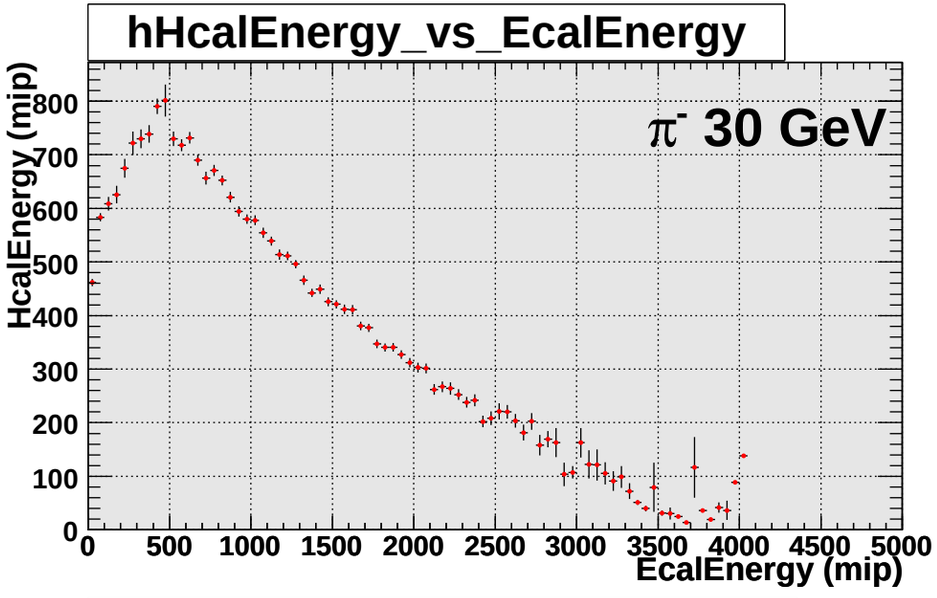
TCMT

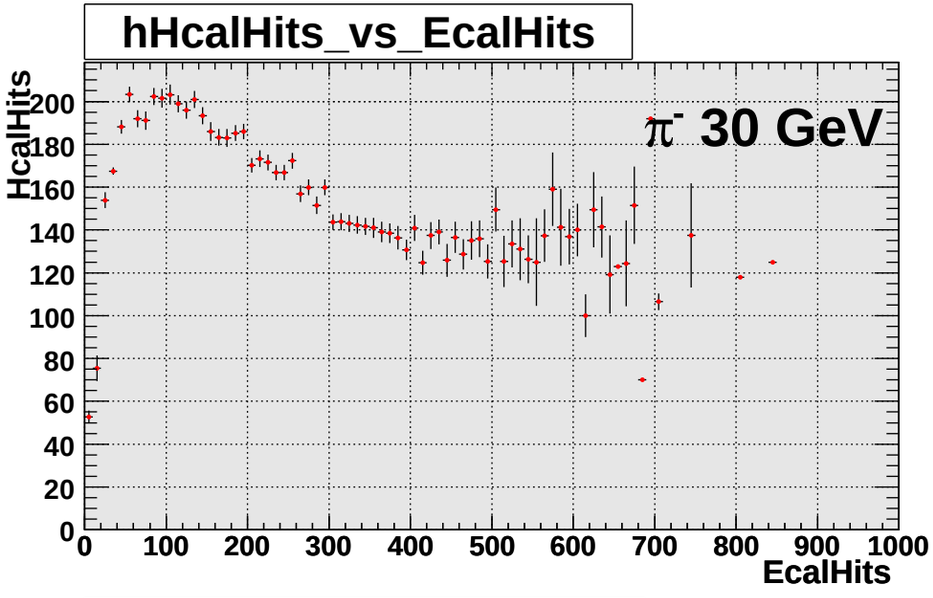


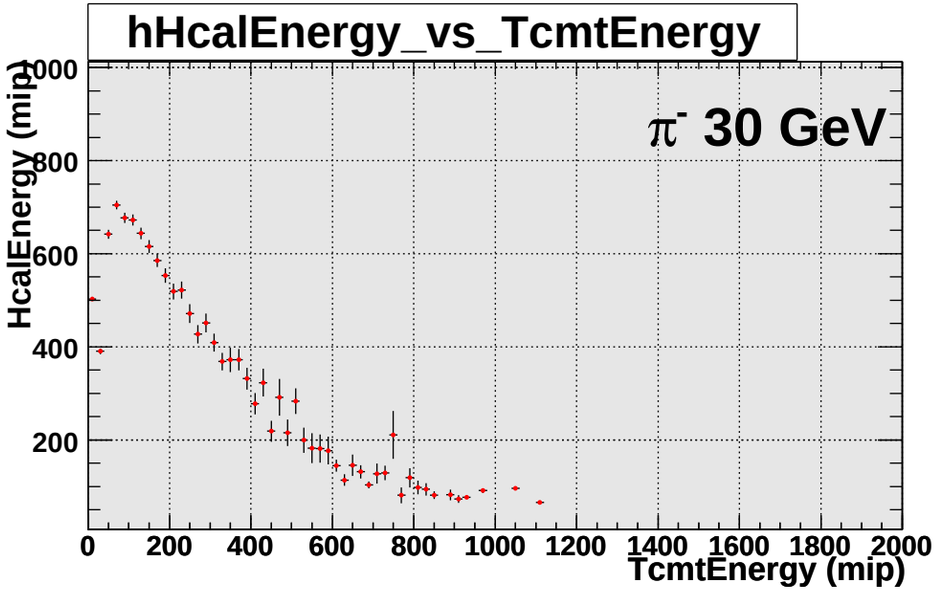


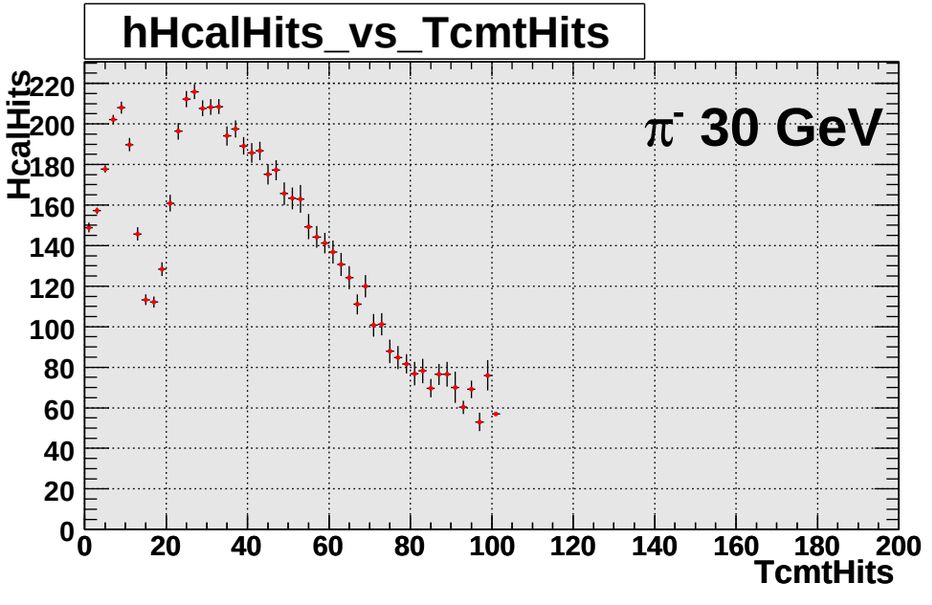
(raw data, no cleaning, no event selection)

ECAL vs HCAL vs TCMT response



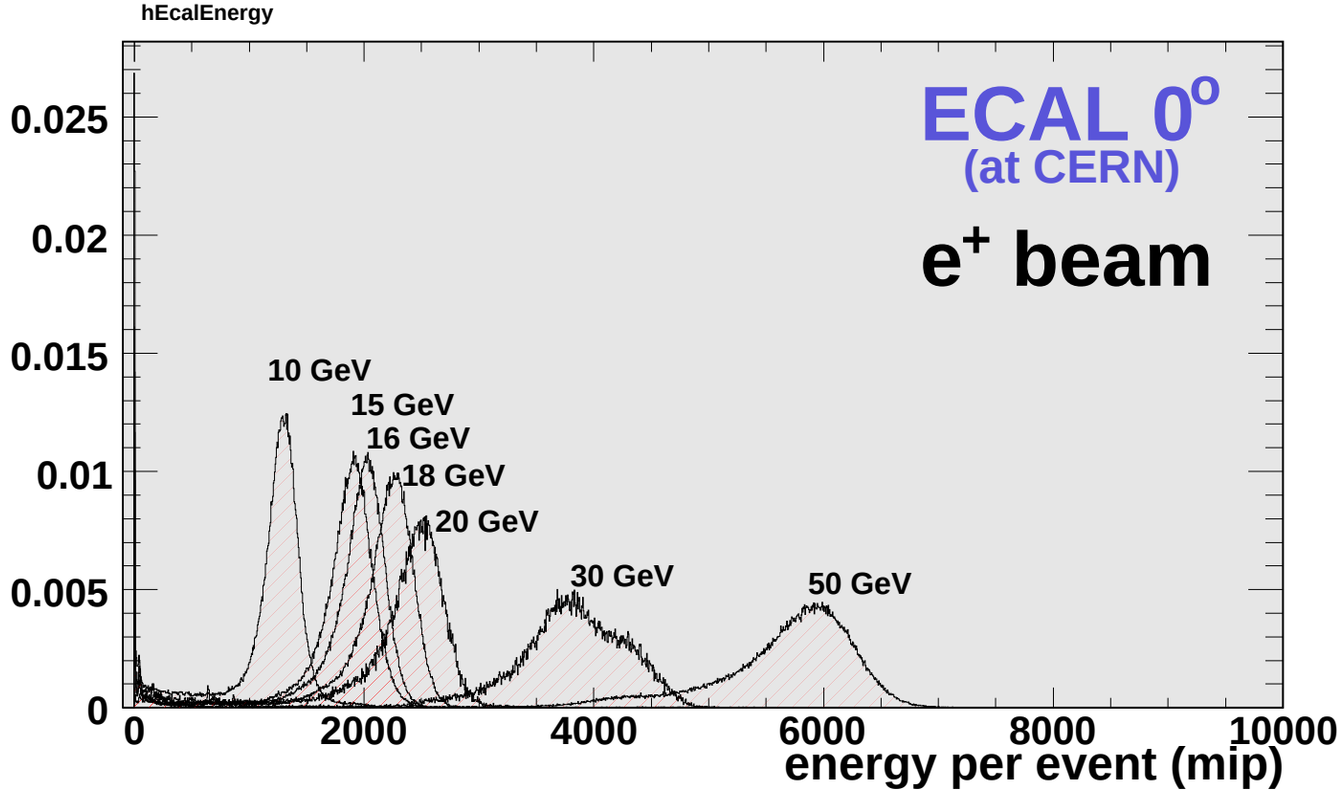






(raw data, no cleaning, no event selection)

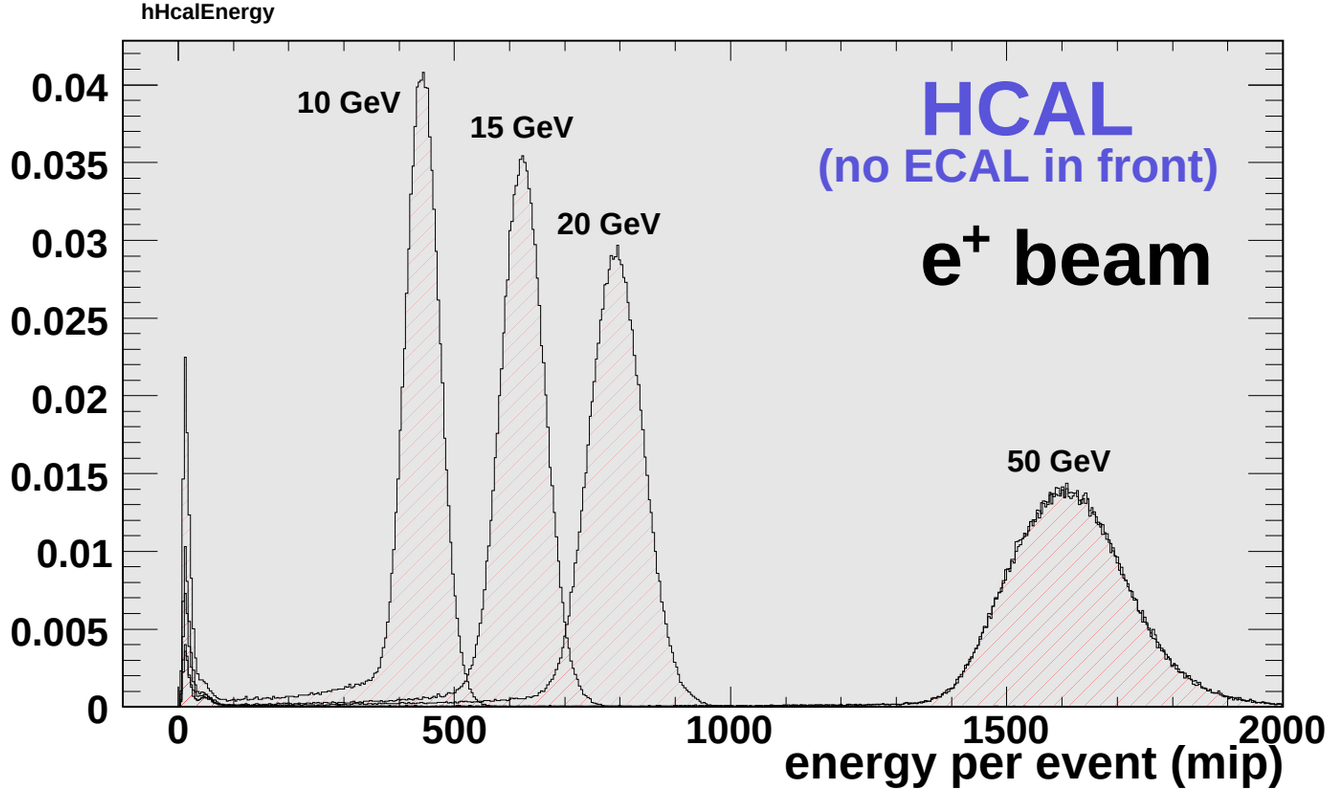
ECAL response to positrons



- most runs with nice and typical behaviour
- at 30 GeV run response affected by noisy/unstable layers

(raw data, no cleaning, no event selection)

HCAL response to positrons

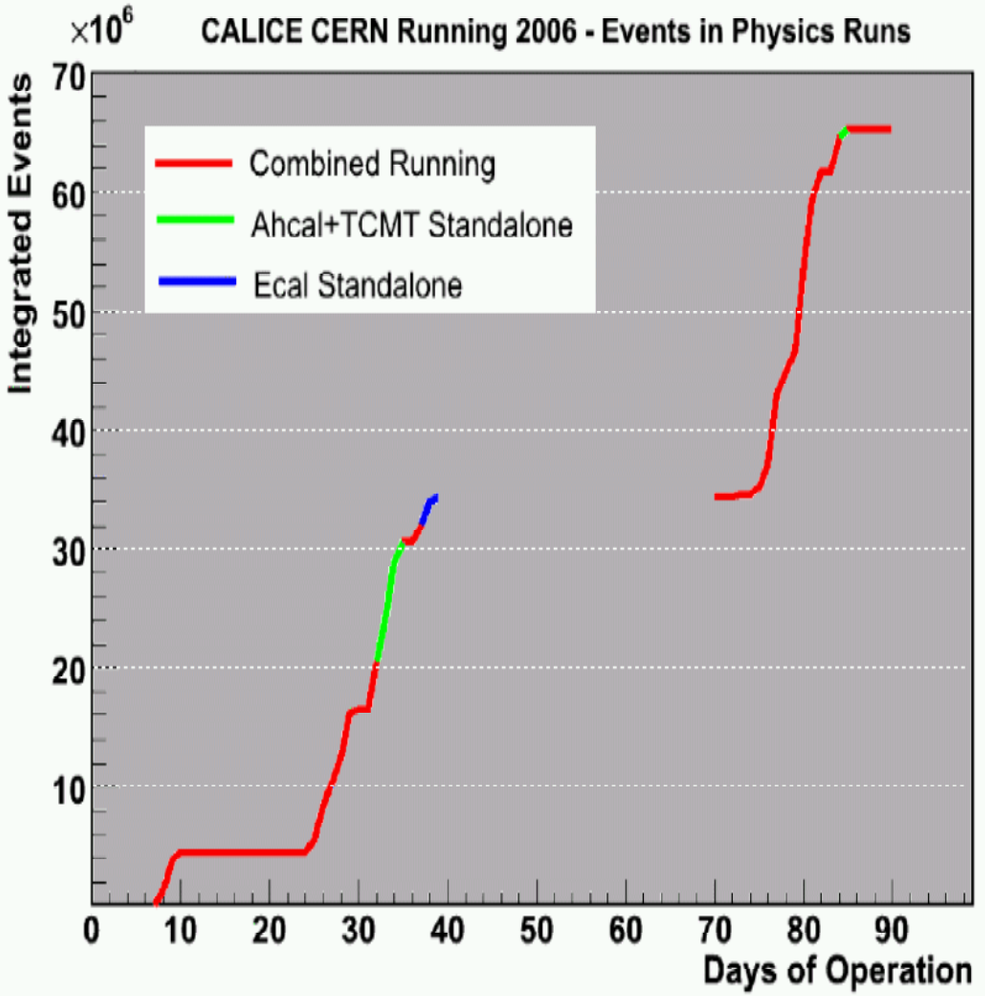


- runs for e/π studies
- also very useful for SiPM saturation studies

(raw data, no cleaning, no event selection)

Testbeam Program at CERN 2006

- total data taking time: $\sim$ 25 days
- total #of people on shift: 56
- beam duty cycle: $\sim$ 60%
- detector up time > 90%
- DAQ showed excellent performance, stable operation and continuous running without failures
  120 Hz max average rate ,
  about 500 Hz peak rate in spill



CALICE Testbeam Plans for 2007-8

- **Si ECAL + scint HCAL/TCMT**

  : complete ECAL(transversally), complete HCAL(longitudinally), mount HCAL on movable/rotatable stage

  : 2nd round of combined testbeam at CERN (summer 2007)

  : **move to FNAL-MTBF in fall 2007**

  todo list

  - data collection with complete instrumentation
  - scans with incidence angle variation
  - increase statistics at low energies (around 10 GeV)
  - extension of the energy range towards smaller energies (down to $\sim$ 2 GeV)
  - proton/antiproton data collection
  - direct comparison with gaseous HCALs under identical beam conditions
  - ... ...

CALICE Testbeam Plans for 2007-8

- **scint ECAL**
  - : testbeam at DESY with small prototype in early 2007
  - : testbeam at FNAL-MTBF with prototype completed, late 2007
- **digital HCAL with RPCs, GEMs**
  - : "slice" test at FNAL-MTBF, early 2007
  - : start production of 1m^3 prototype, early 2008 (?)
  - : join combined testbeams at FNAL-MTBF, late 2008 (?)
- **digital HCAL with μMegas**
  - : build single chamber(s), first tests at CERN in 2007
  - : build/test 1m^2 chamber(s) in 2008

Summary

- **an experiment at the ILC**
  - : strict requirements for vertex, tracking and calorimetric detectors
  - : a lot of R&D effort needed (= money $\times$ time $\times$ bright manpower $\times$ facilities)

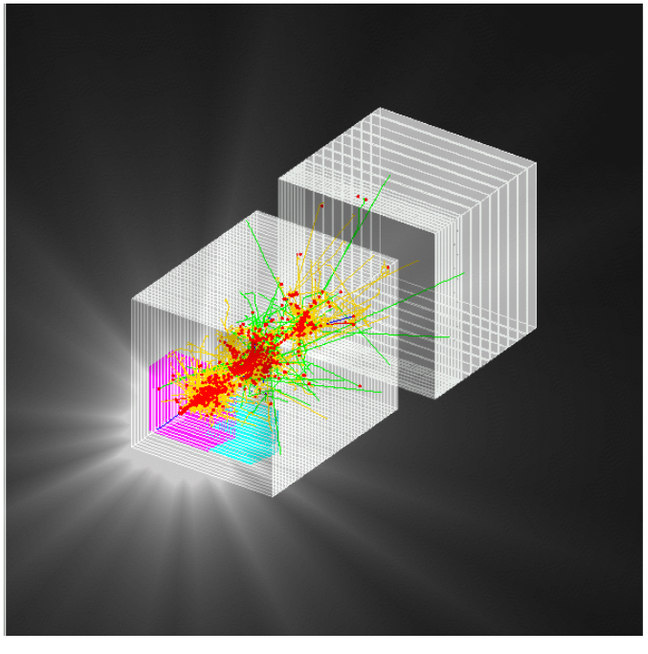
- **CALICE Collaboration**
  - : to conduct the R&D for calorimetry
  - : **the main goal**

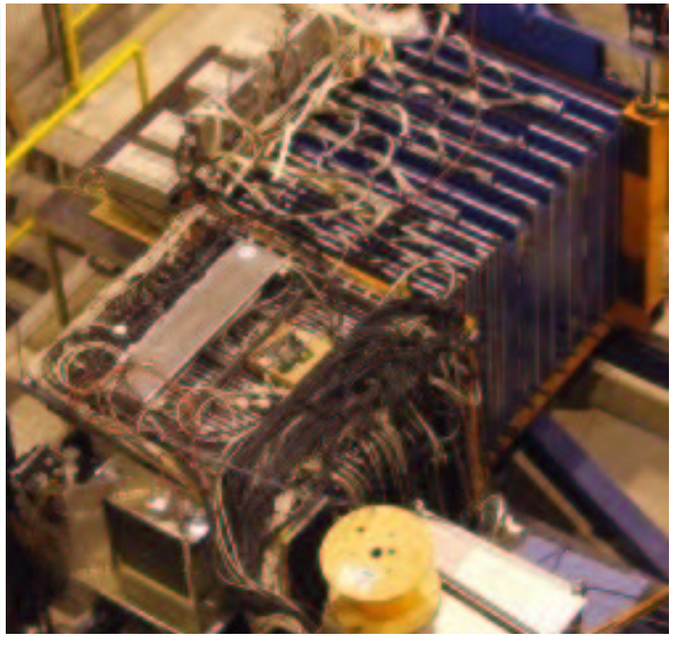
    highly granular EM and HADR calorimeters to allow very efficient pattern recognition for excellent shower separation and pid within jets to provide excellent jet reconstruction efficiency

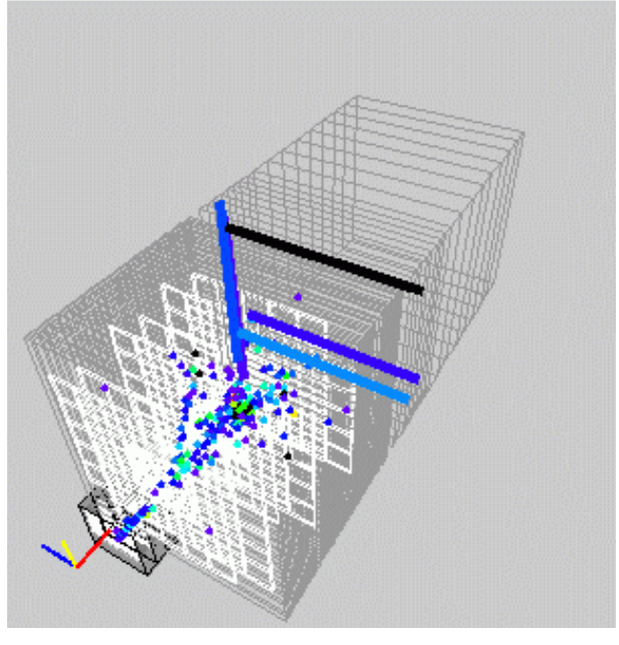
  - : concepts-prototype studies
    - ▷ Si/W ECAL, scint ECAL, scint analogue HCAL, gaseous digital HCALs
    - ▷ loop over simulation-testbeam-analysis chain started
    - ▷ a lot to come, a lot to learn

Prototyping cycle

SIMULATION **REALITY** **DATA**







(slide by E.Garutti)

Summary

- **CALICE Testbeam Program 2005-6**

  : several rounds of technical and physics runs at DESY and CERN

  : very busy and productive period, huge amount of data collected

  : possible only with huge and constant effort of all involved

- **Plans for 2007-8**

  : expect to continue effort at the same pace

  : several rounds of testbeams at DESY, CERN, FNAL planned for development studies, technical runs and physics data collection

  : we wish/plan to move the "center-of-gravity" of our program to FNAL-MTBF