CALICE silicon-tungsten electromagnetic calorimeter, 1×1 cm^2 granularity prototype testbeam and results

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Outline

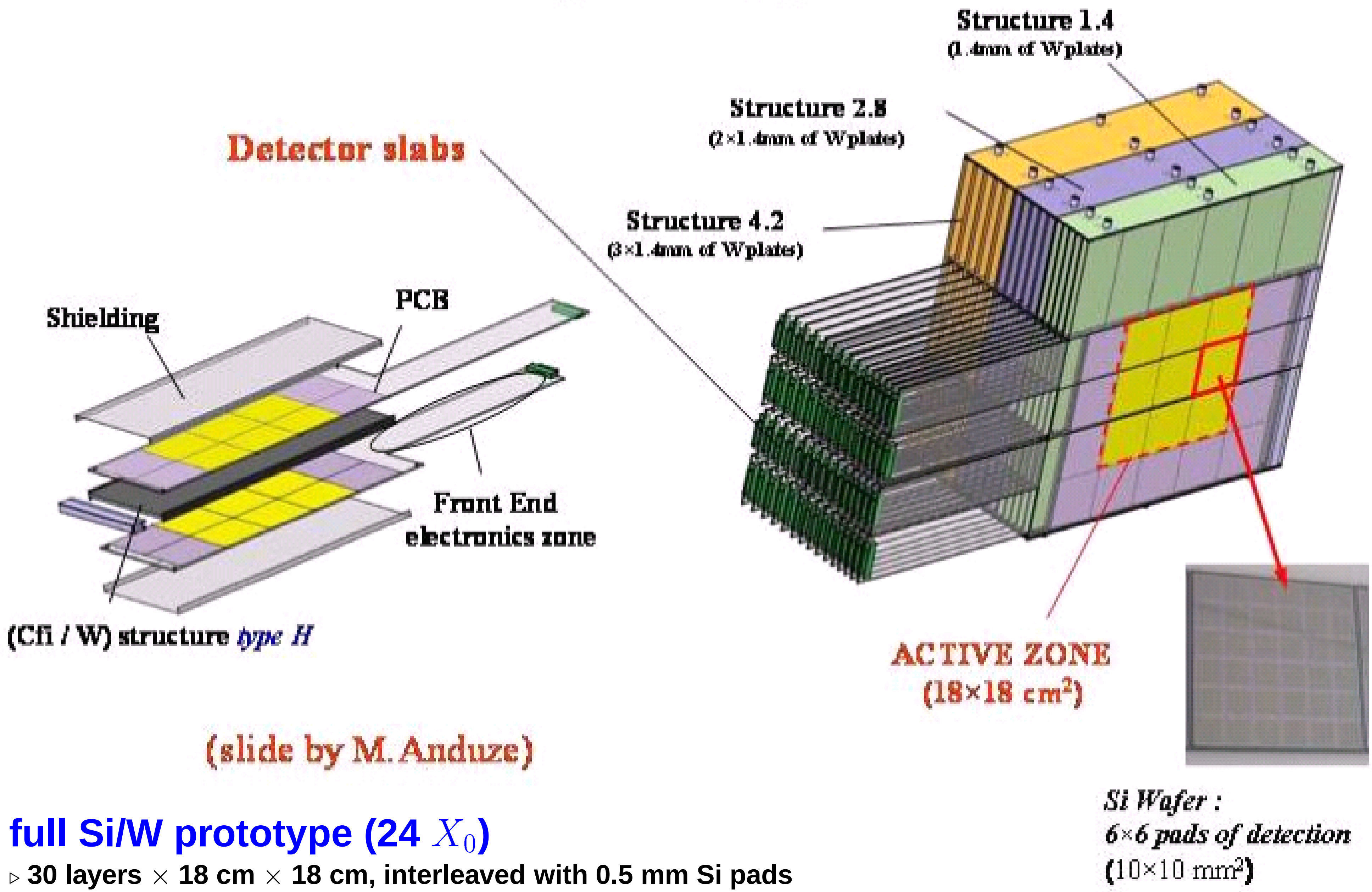
- **General**
- **Si/W prototype**
- **Testbeam results**
  - : position resolution, tracking performance
  - : response map, inhomogeneity
  - : transverse containment, Moliere radius
- **Summary**

General

- **"1/3" of CALICE Si/W ECAL prototype**
  - 3024 channels of 1 $\times$ 1 cm^2, 14 layers, 7.2 X_0
  - first testbeam at DESY with e^- (Jan/Feb05), a lot of data collected

- **data analysis**
  - comprehensive understanding and debugging of the system before the next round of testbeams
  - also pilot-reference studies to be repeated as detector grows
  - results to discuss from studies on
    - position resolution, tracking performance
    - response map, inhomogeneity
    - transverse containment, Moliere radius
    - data-simulation comparison

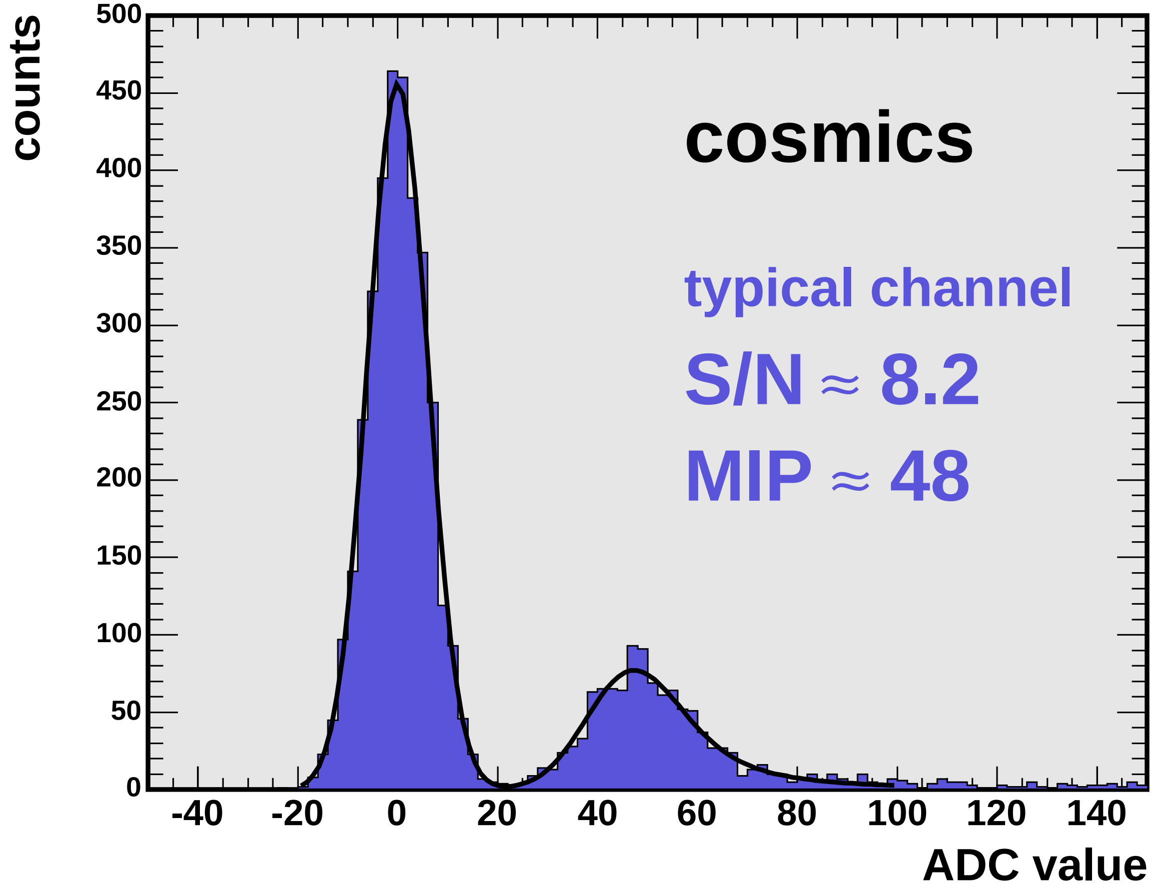
CALICE ECAL prototype



full Si/W prototype (24 X_0)

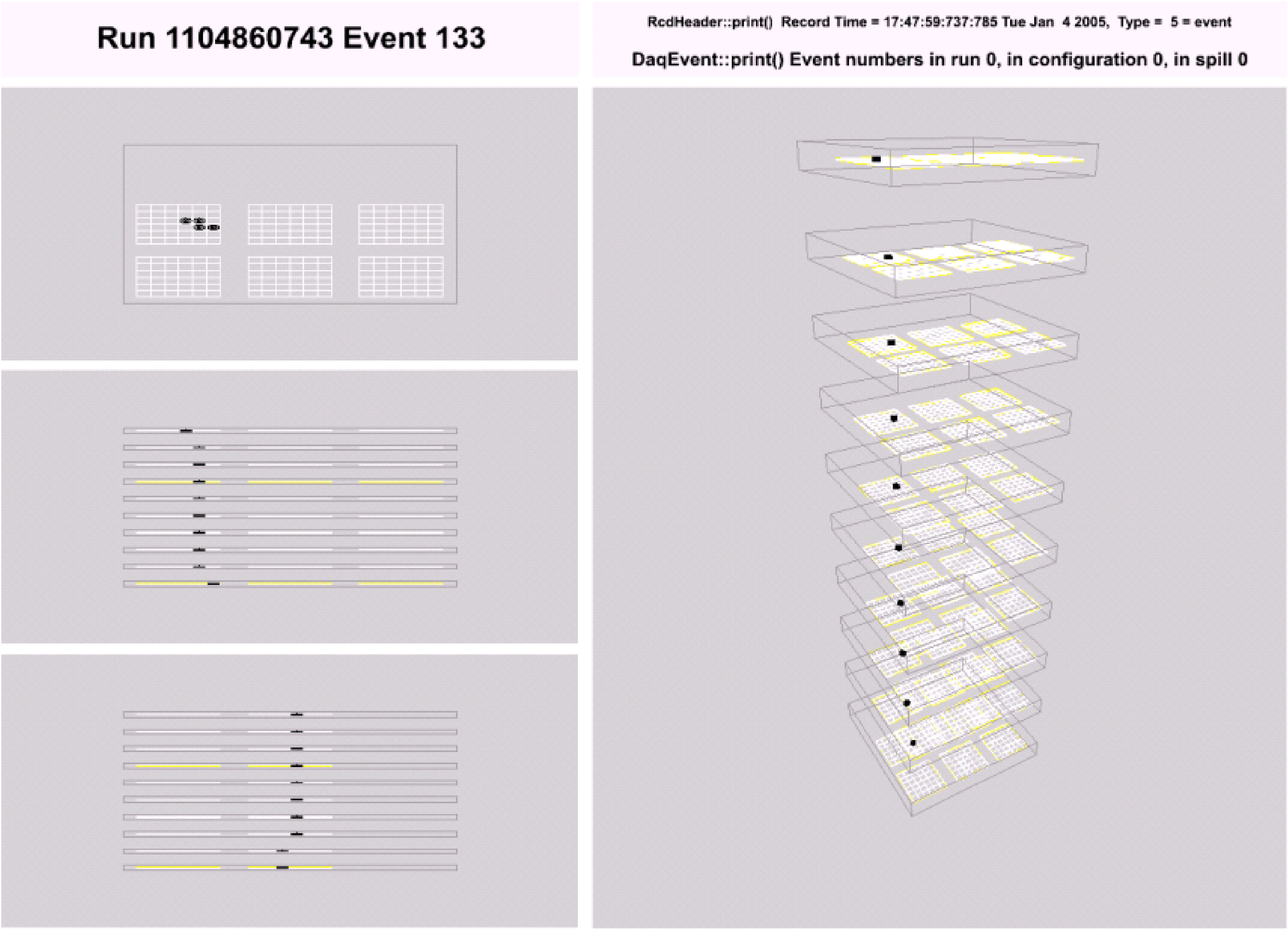
- 30 layers $\times$ 18 cm $\times$ 18 cm, interleaved with 0.5 mm Si pads
- W absorber, 10+10+10 layers, 1.4 mm:2.8 mm:4.2 mm thick per respective layer
- readout by **1×1 cm^2 cells, total: 9720 channels**

Calibration with cosmics



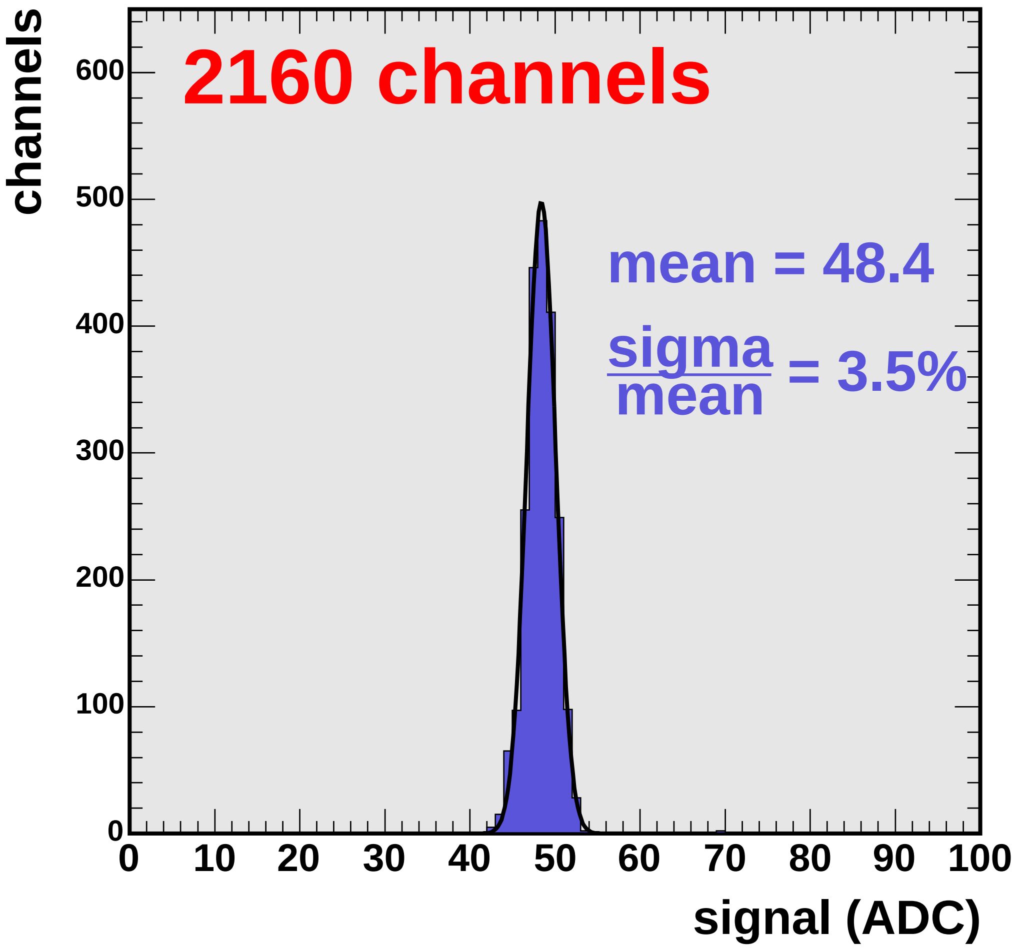
▷ **a typical channel: gaussian noise, landau signal**

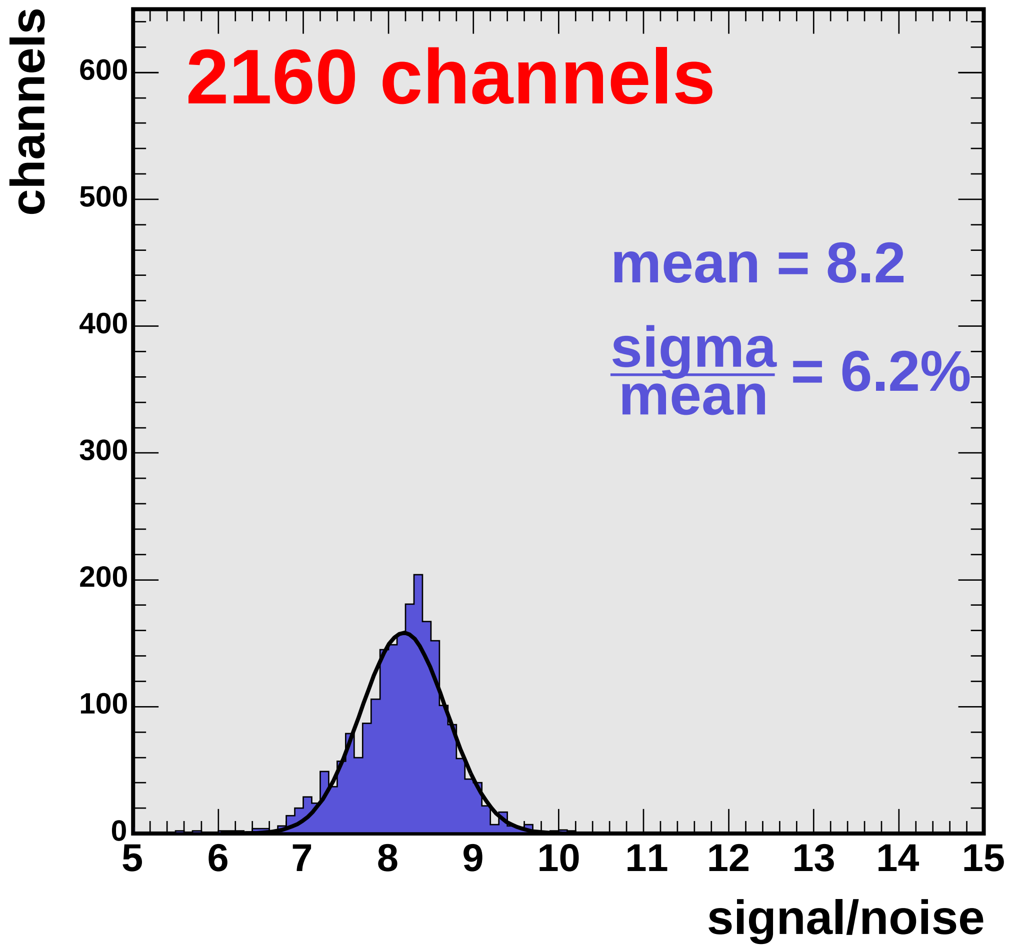
Cosmics



Run 1104860743 Event 133
RcdHeader::print() Record Time = 17:47:59:737:785 Tue Jan 4 2005, Type = 5 = event
DaqEvent::print() Event numbers in run 0, in configuration 0, in spill 0

Calibration with cosmics





▷ **10 layers (2160 channels) calibrated with cosmics (1 Mevents)**

(LLR-Paris, Dec04)

CALICE-ECAL testbeam at DESY

- **· "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, **cellsize: 1 $\times$ 1 cm^2**,
  total: **3024 channels**

  : first testbeam at DESY with electrons during Jan/Feb05

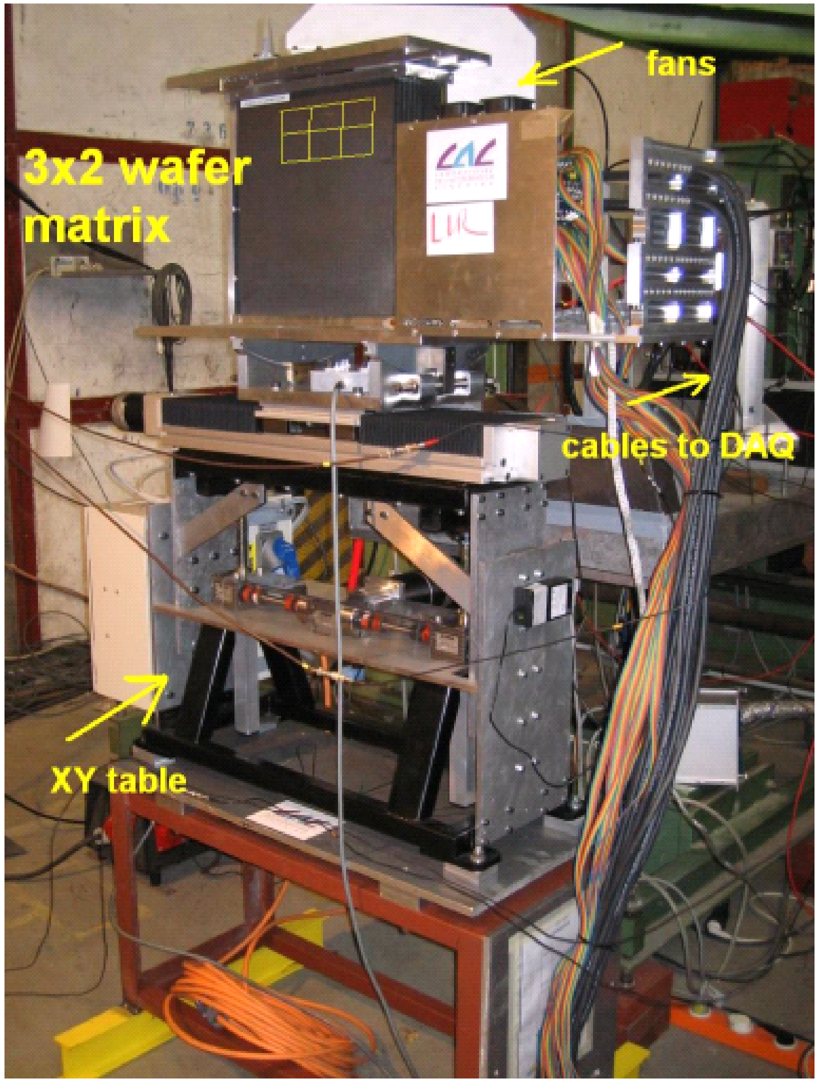
- **· in summary (configurations: position $\times$ energy $\times$ angle)**

  : 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°)

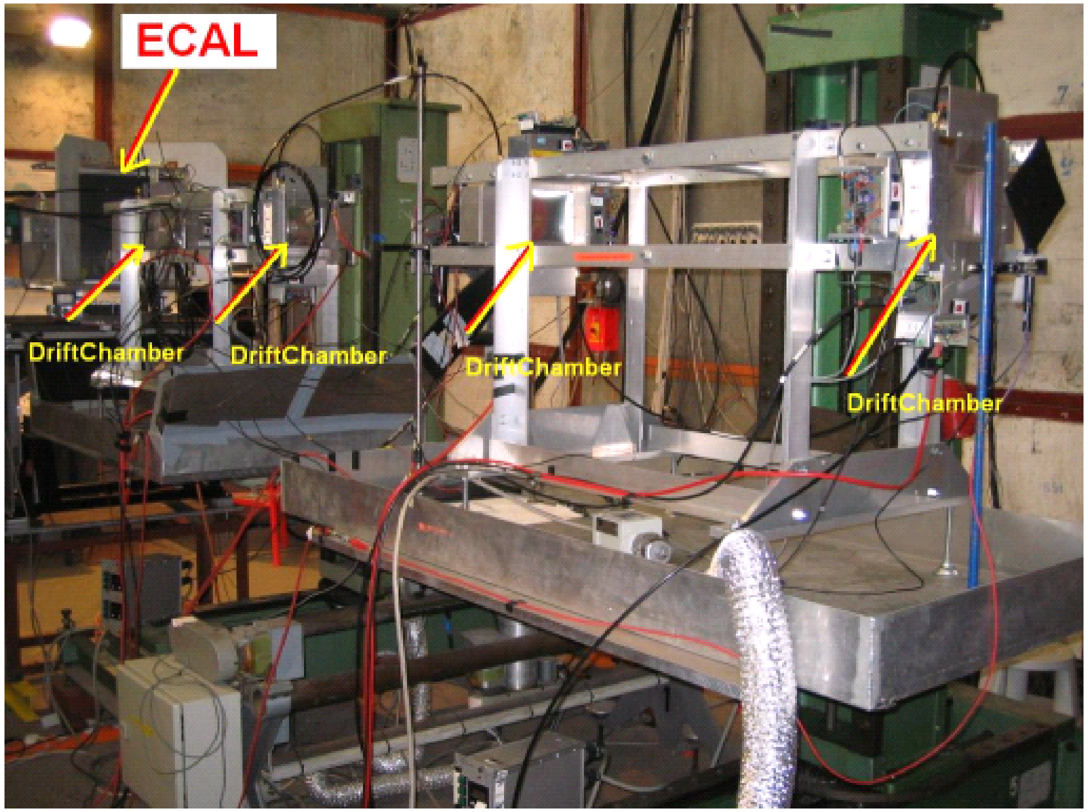
  : total: $\sim$ 25 Mevents ($\sim$ 230 GB)

CALICE-ECAL testbeam at DESY

ECAL

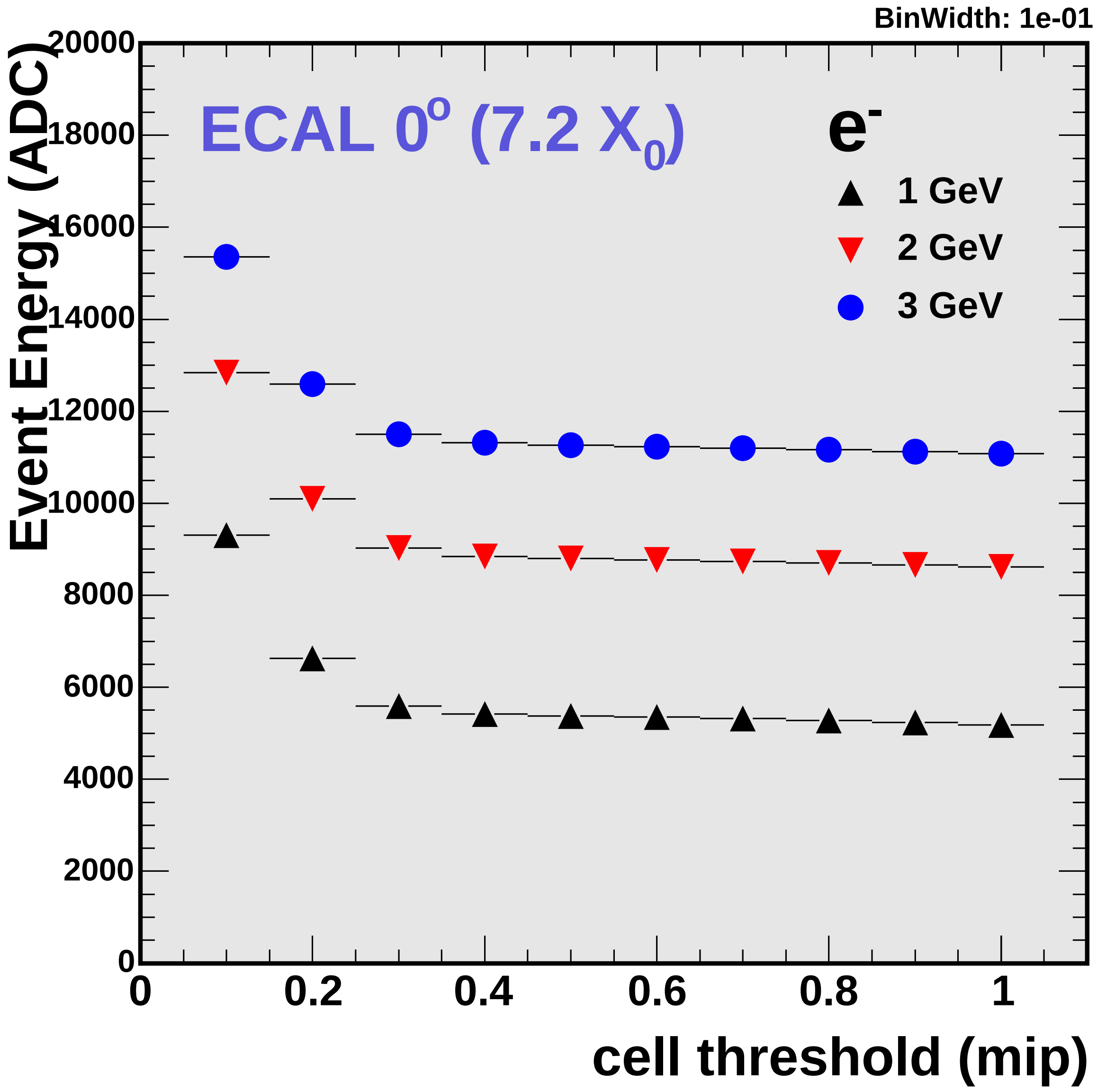


layout at DESY T21



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

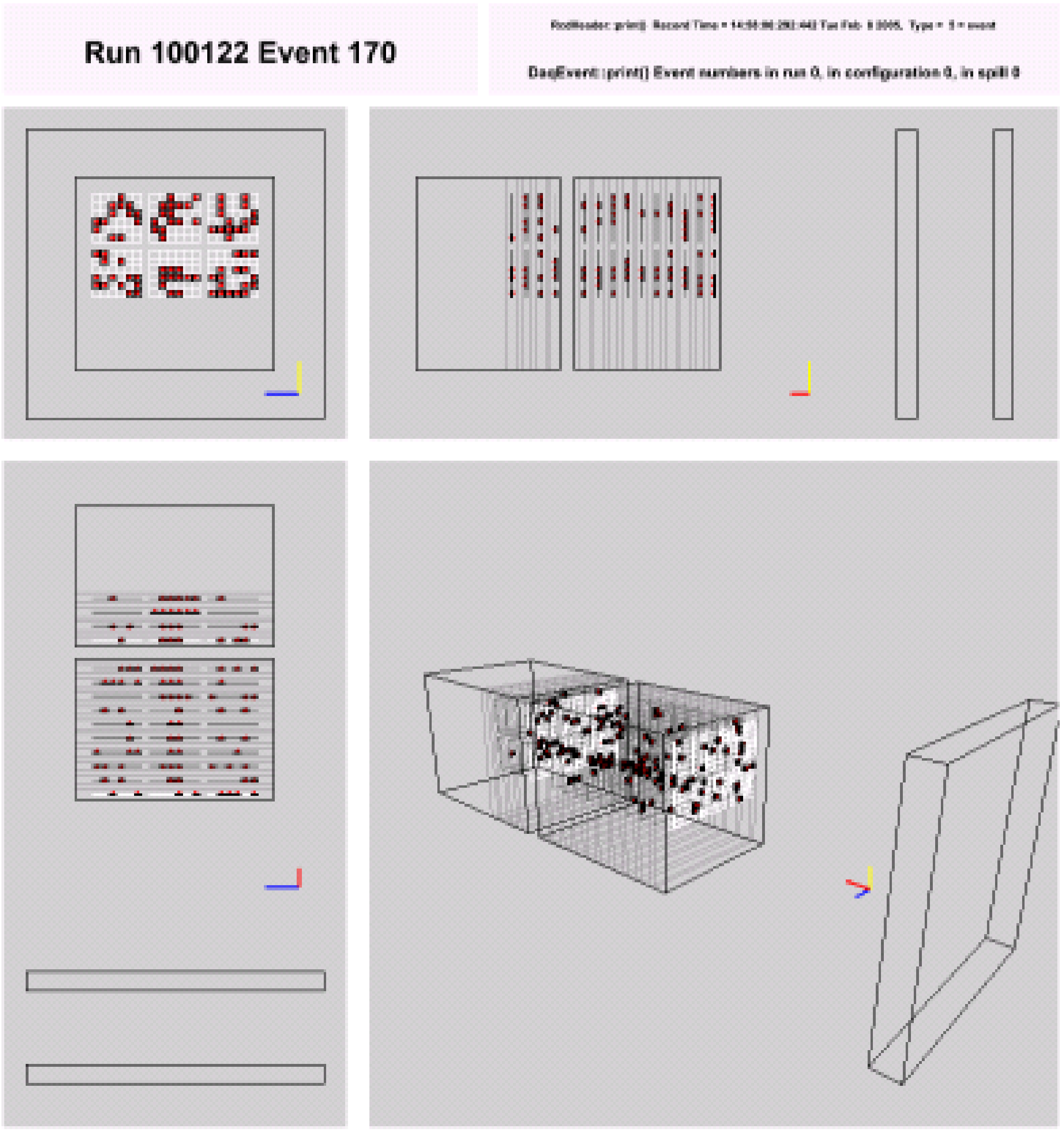
"Response" vs cell threshold



▷ **safe limit a threshold around 0.5 - 0.6 mip**

▷ **following analysis with threshold = 0.5 mip**

"Tracking Calorimetry"

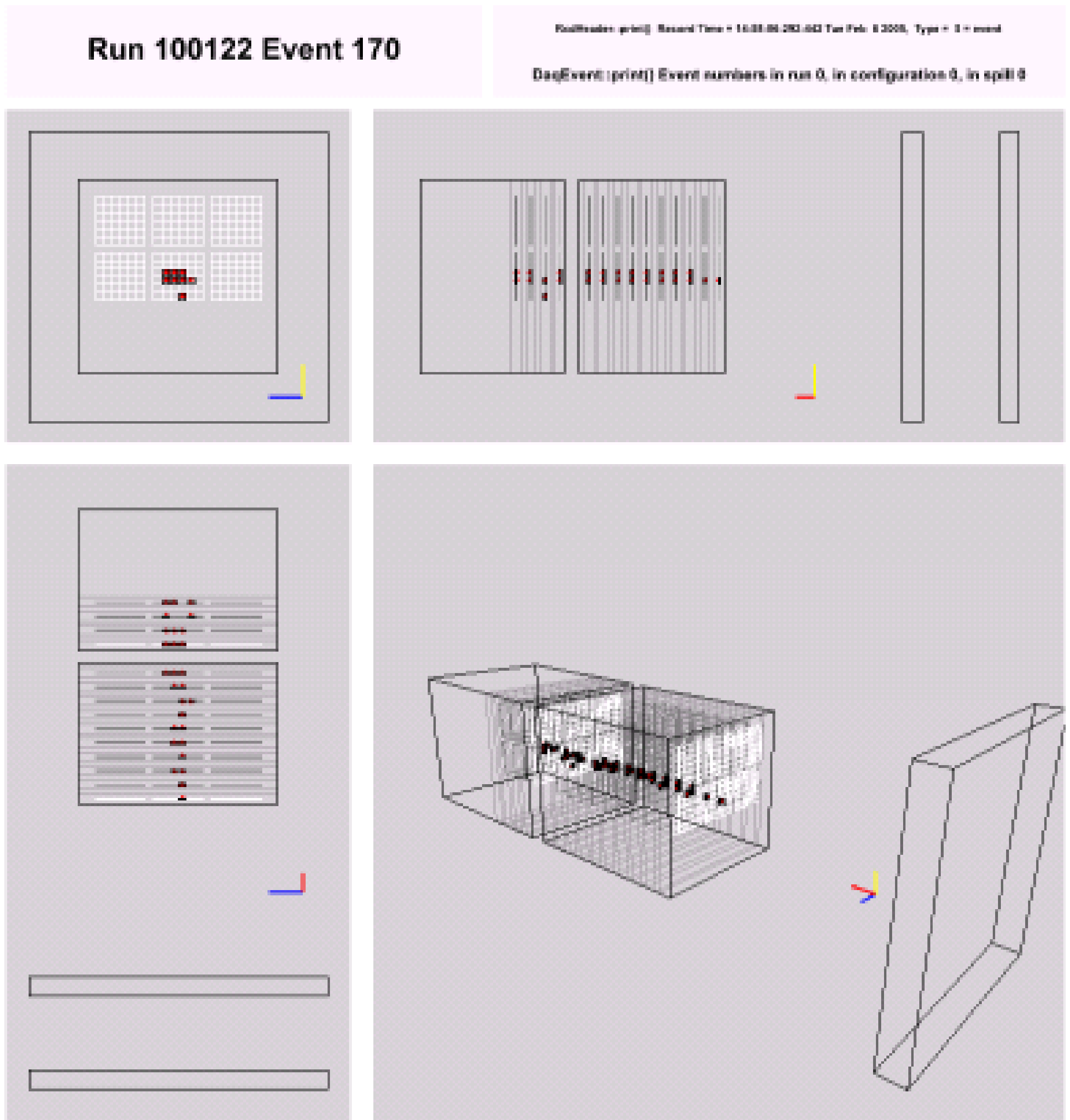


(not to scale)

e^{-} 1 GeV

cell threshold = 0.2 mip

"Tracking Calorimetry"

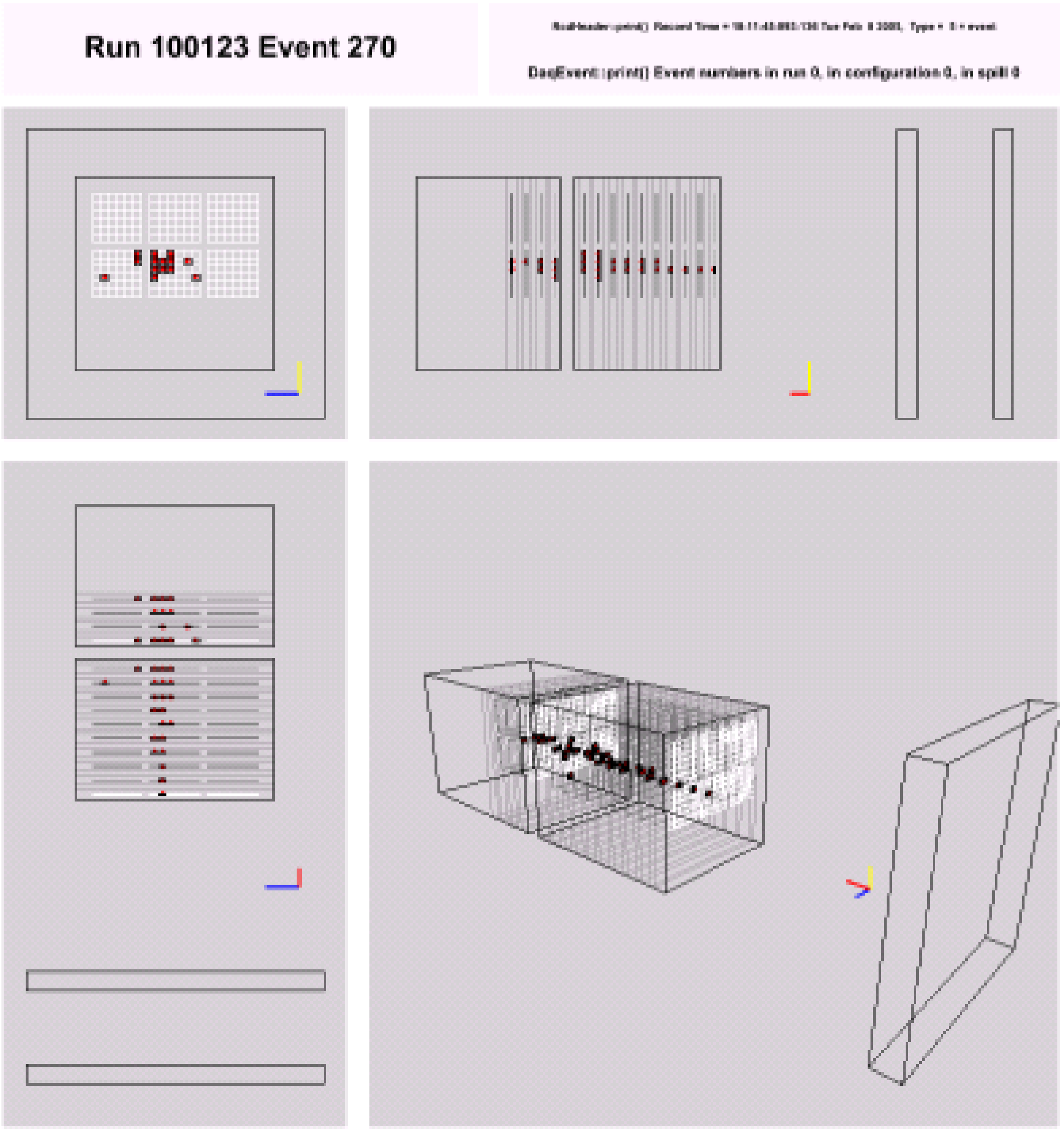


(not to scale)

e^- 1 GeV

cell threshold = 0.5 mip

"Tracking Calorimetry"

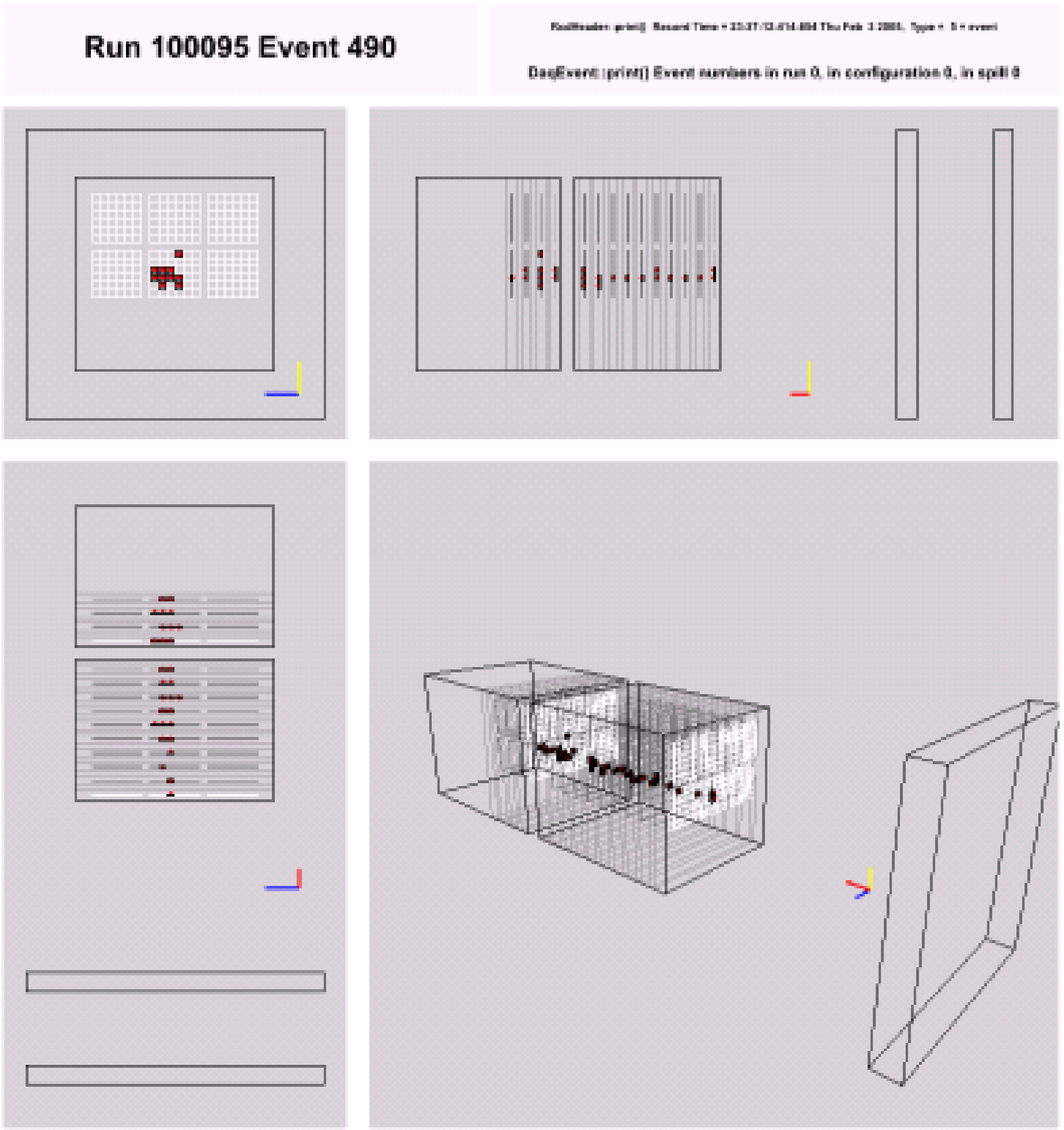


(not to scale)

e^{-} 2 GeV

cell threshold = 0.5 mip

"Tracking Calorimetry"

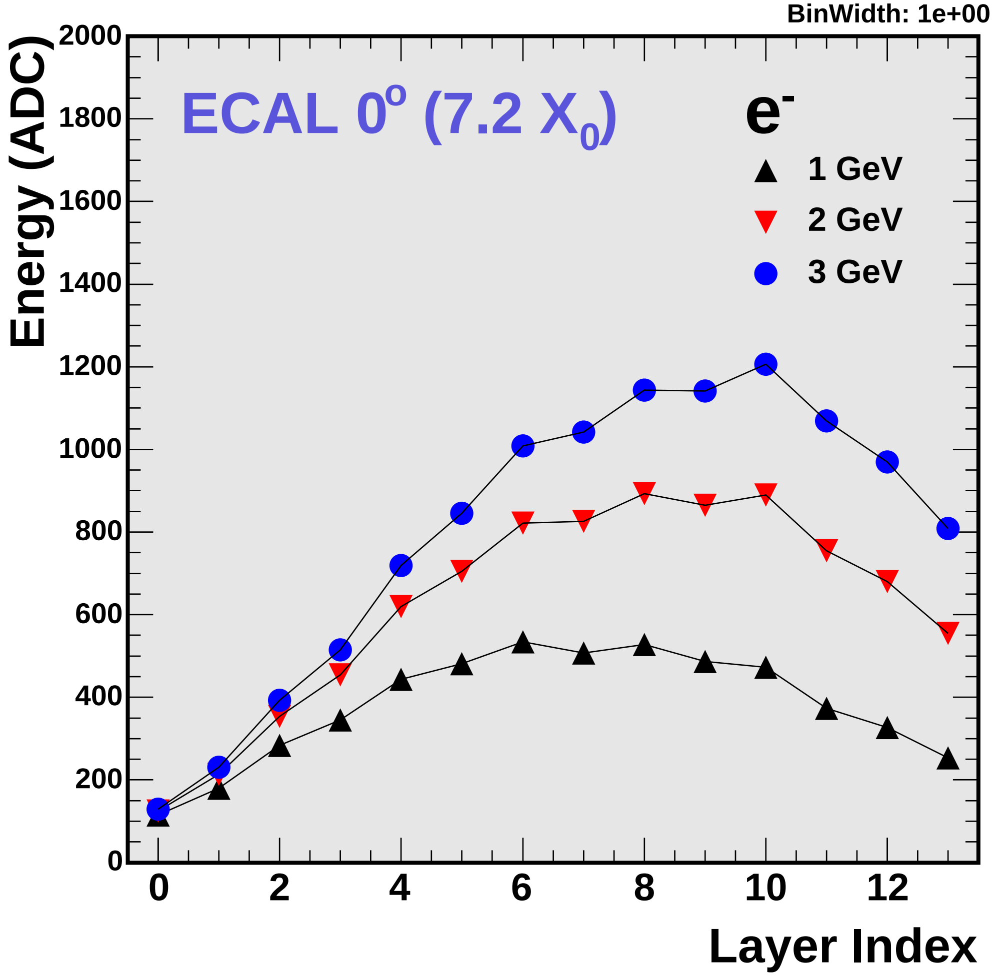


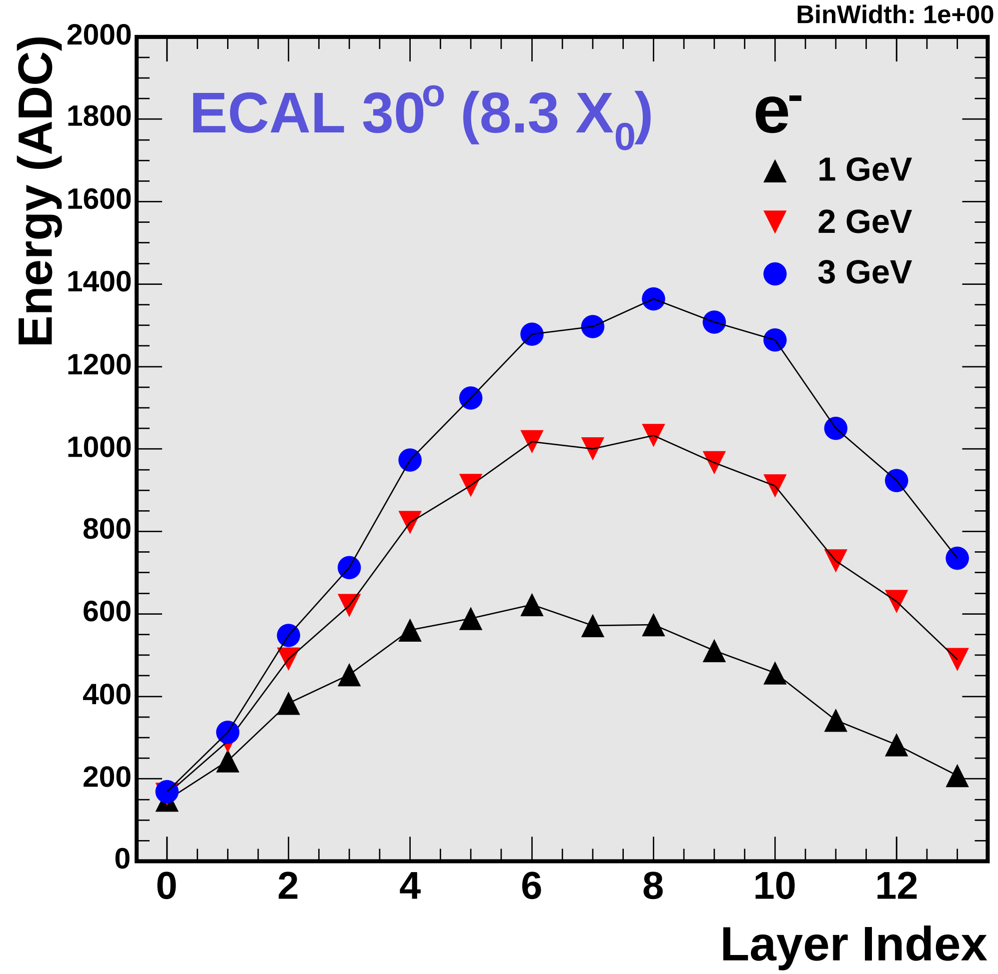
(not to scale)

e⁻ 3 GeV

cell threshold = 0.5 mip

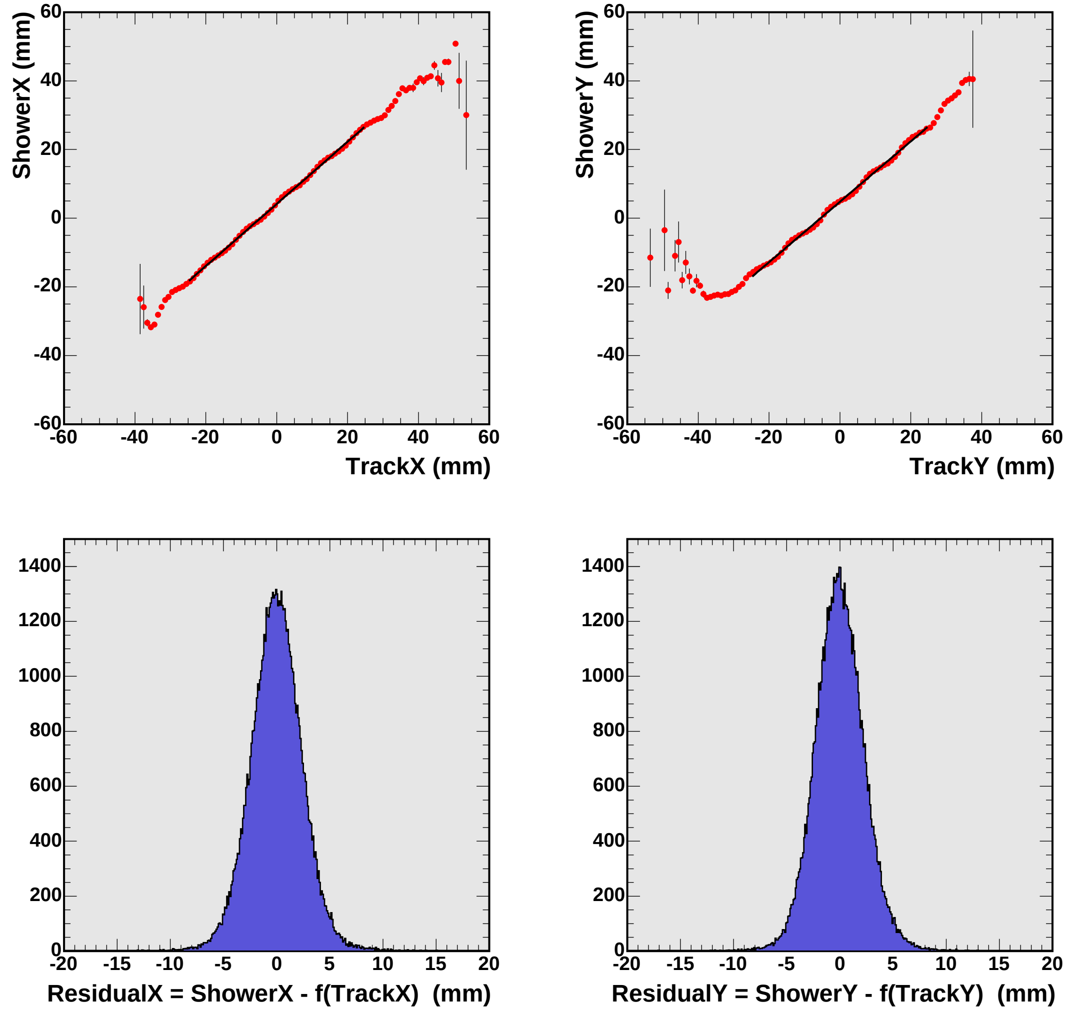
Shower longitudinal profile





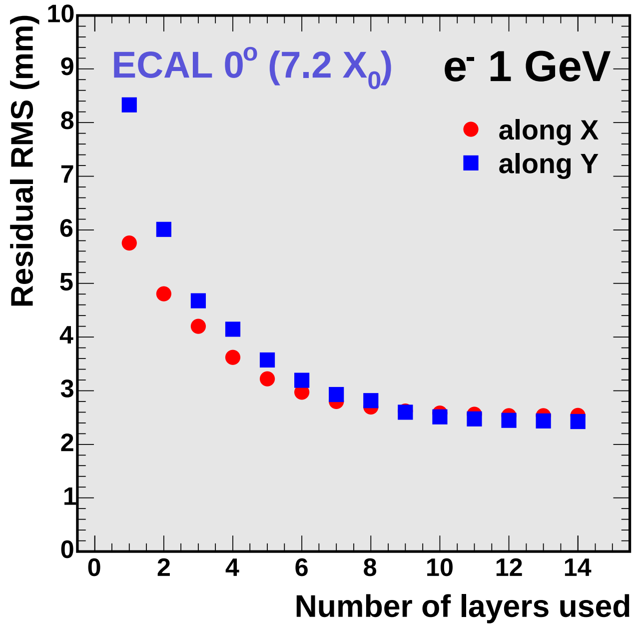
- ▷ shower maximum is contained
- ▷ odd/even asymmetry of construction observed
- ▷ showers better contained at 30°

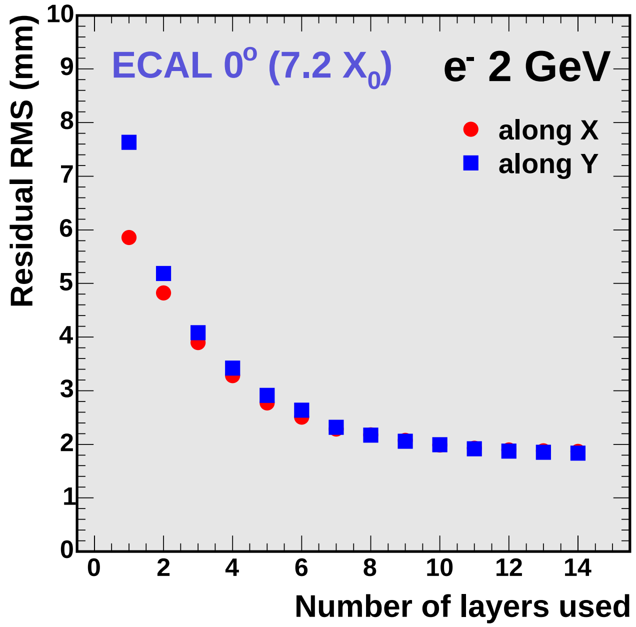
Tracking - Residuals

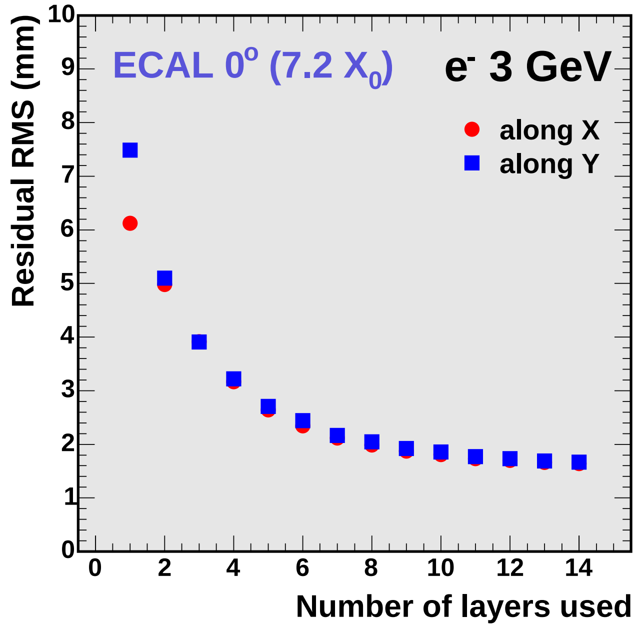


- **ShowerX,Y from barycenter in ecal**
- **TrackX,Y from 4 drift chambers**

Position resolution

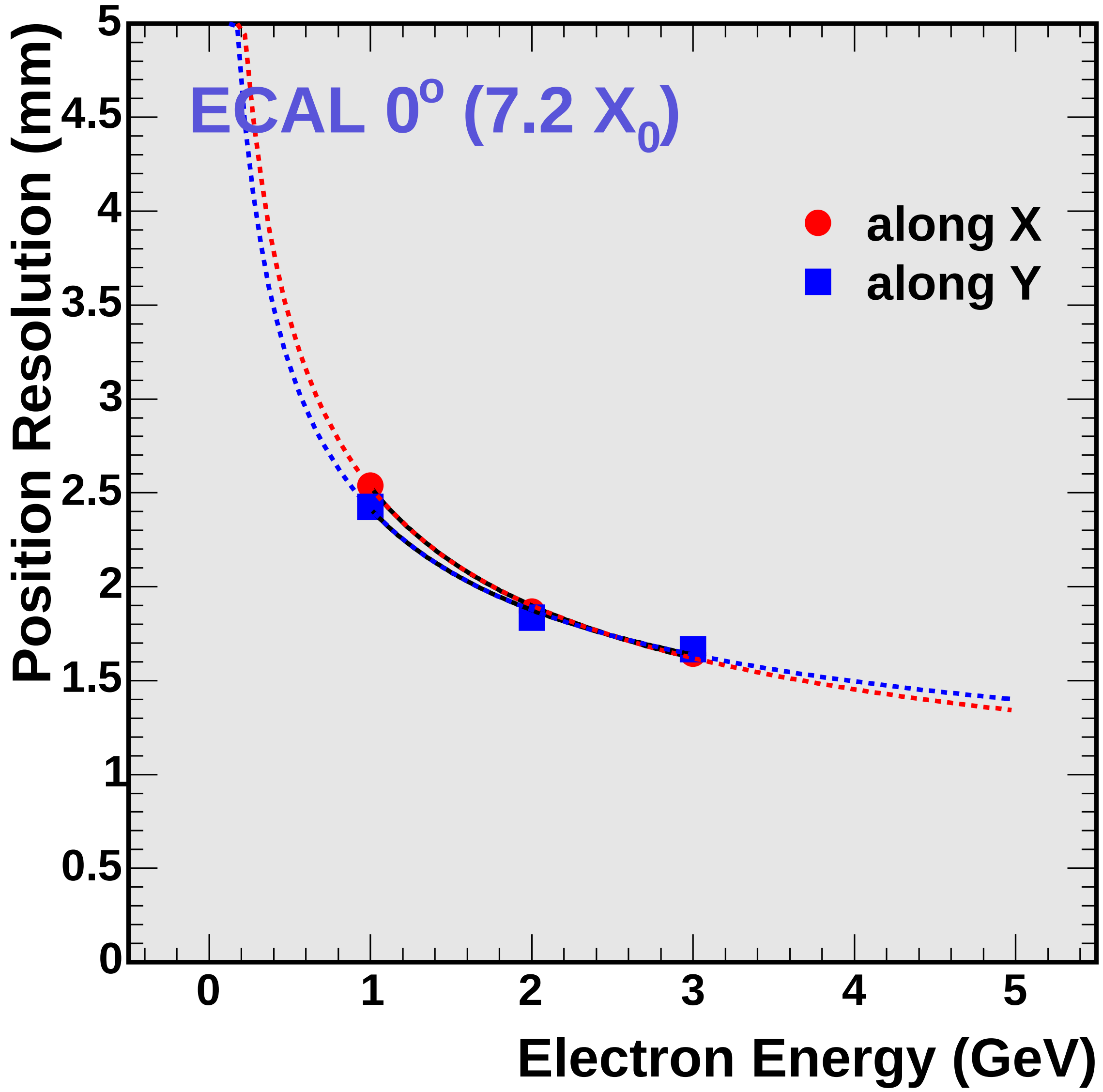






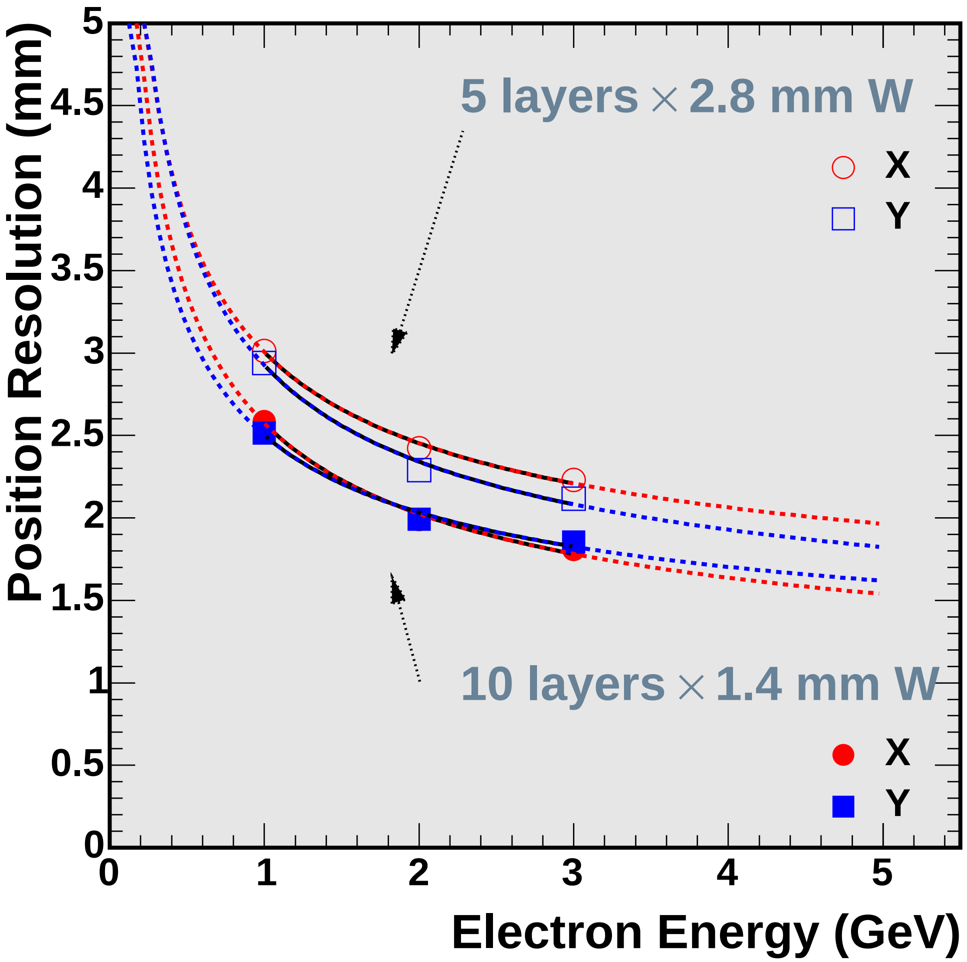
▷ **Residual RMS as a function of the number of ecal layers used**

Position resolution



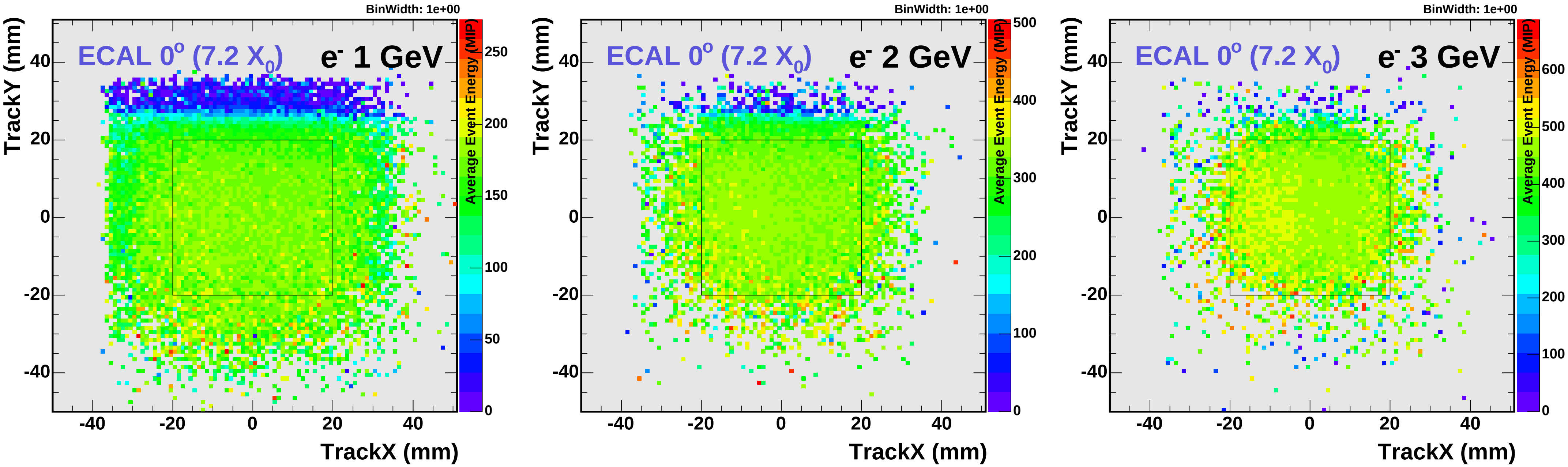
▷ **highly granular ECAL** ⟶ **excellent position resolution**

Position resolution - undersampling

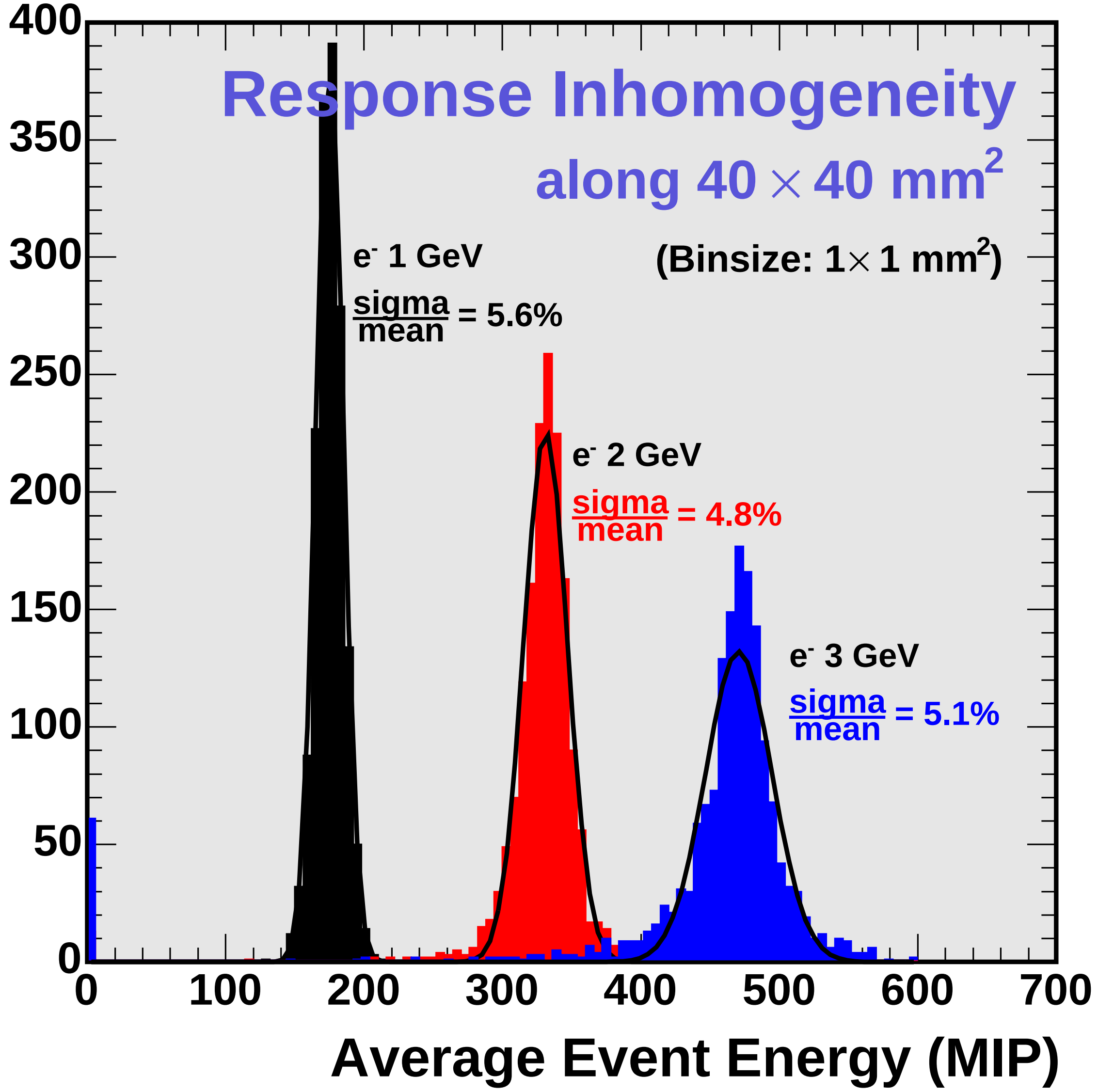


- do tracking by using only hits from every 2nd layer
- to investigate the tracking performance of an ecal with 5 layers $\times$ 2.8 mm W
  (instead of 10 layers $\times$ 1.4 mm W)
- expect position resolution to degrade by factor $\frac{\sigma_5}{\sigma_{10}} \approx \frac{\sqrt{10}}{\sqrt{5}}$

Response map - center of wafer

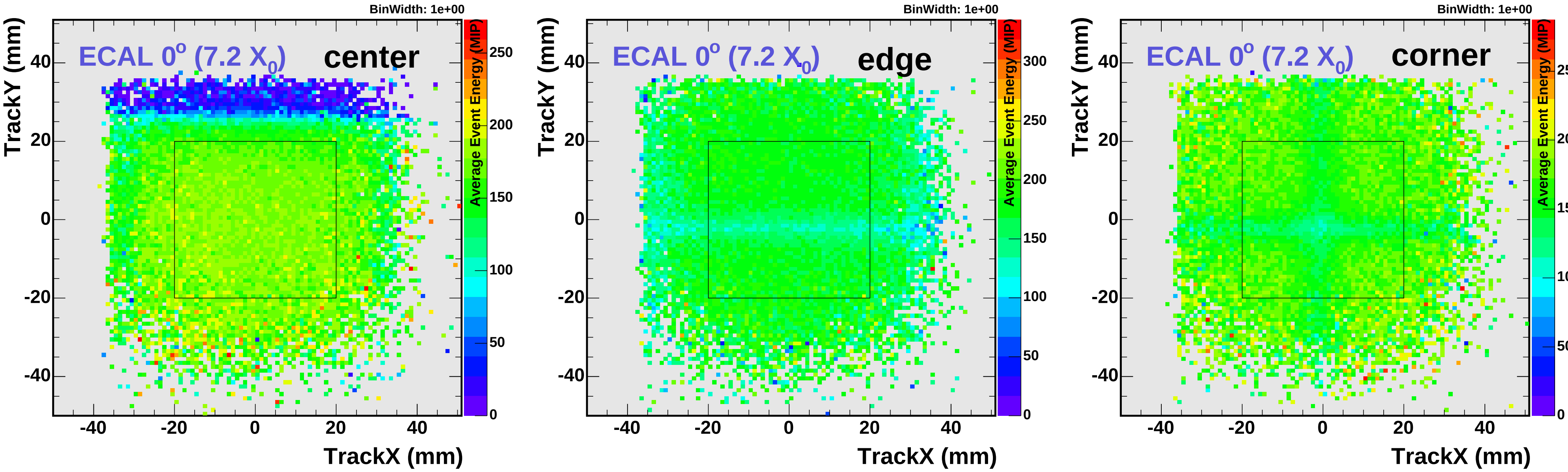


Response Inhomogeneity

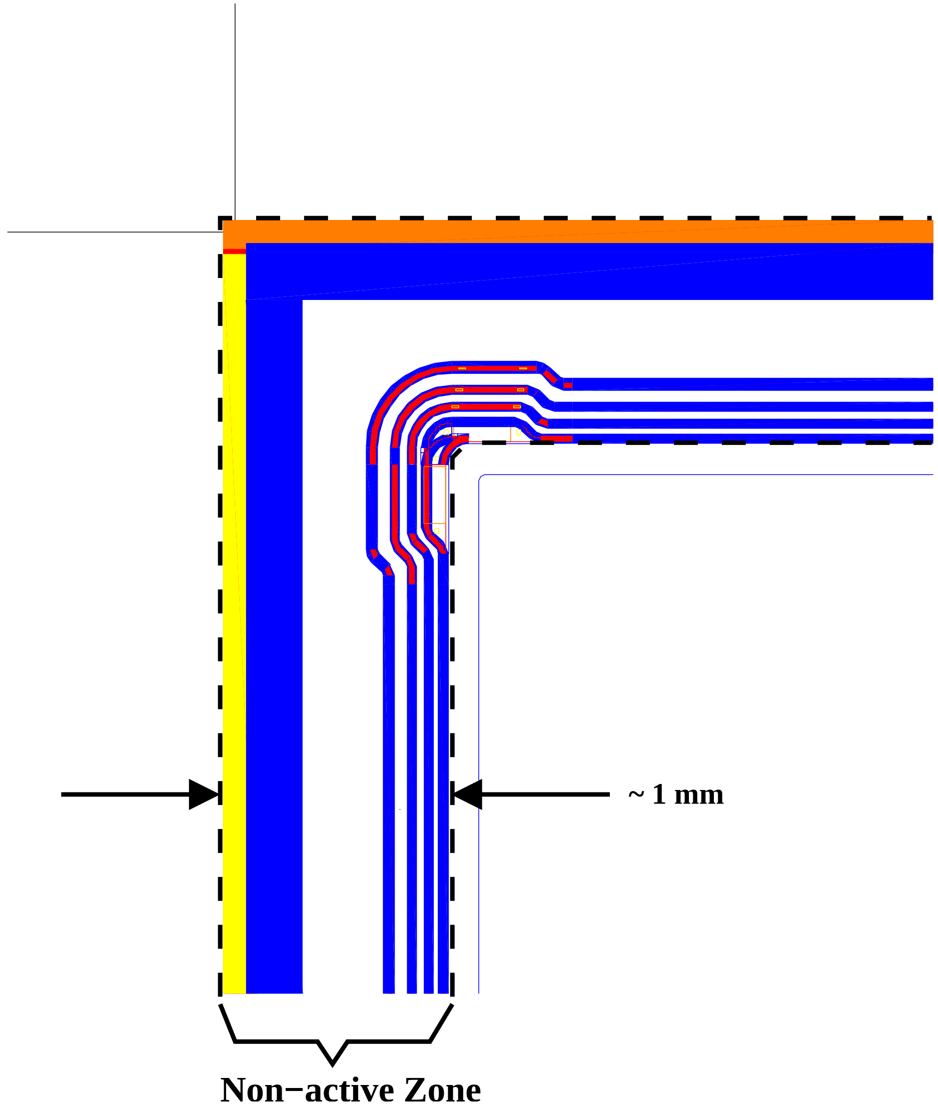


▷ **response variation around the center of wafer**

Response map - center/edge/corner of wafer

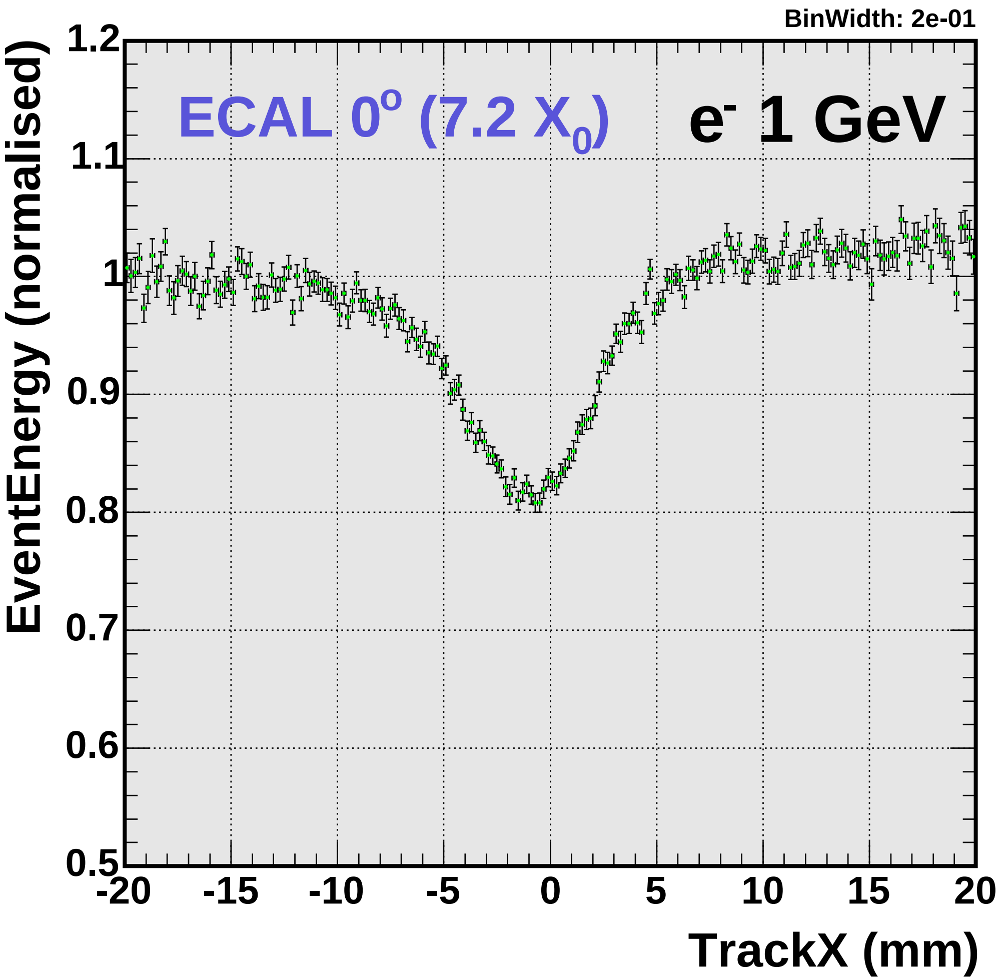


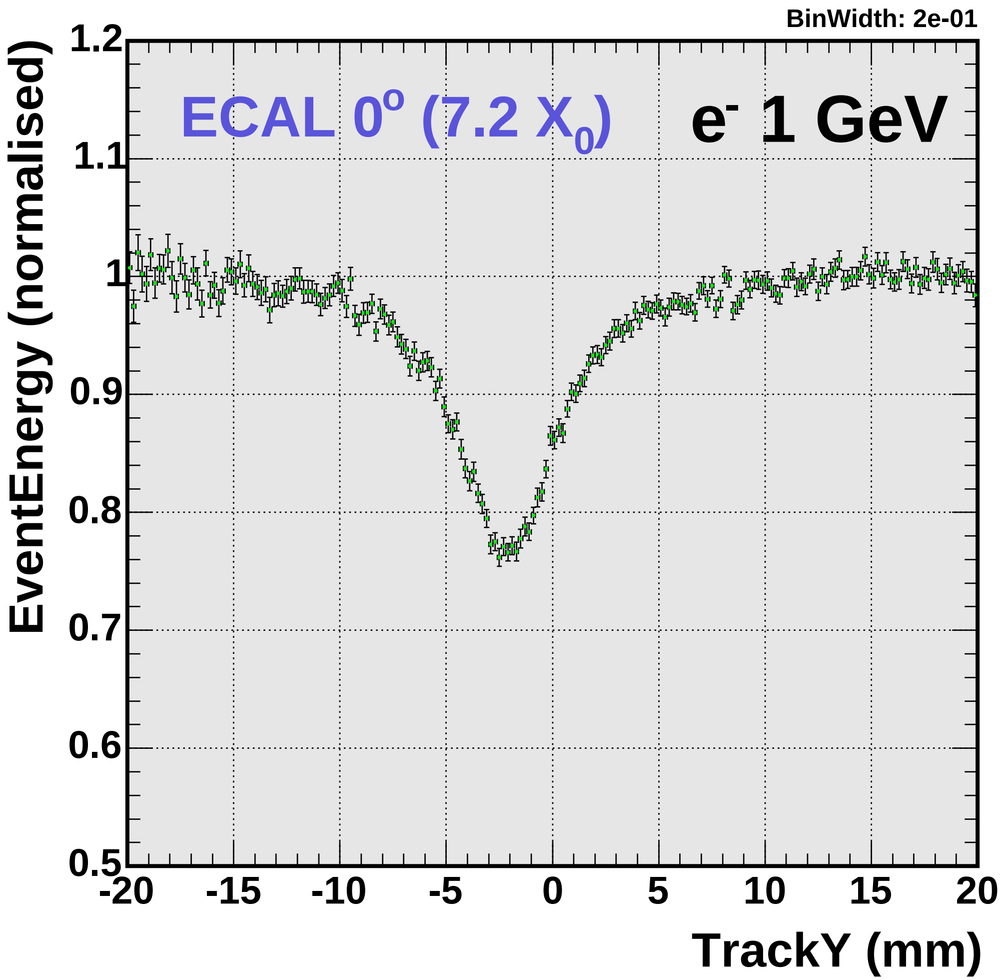
Wafer border



▷ **(C.LoBianco, LC-DET-2004-007)**

Position scan along wafer borders





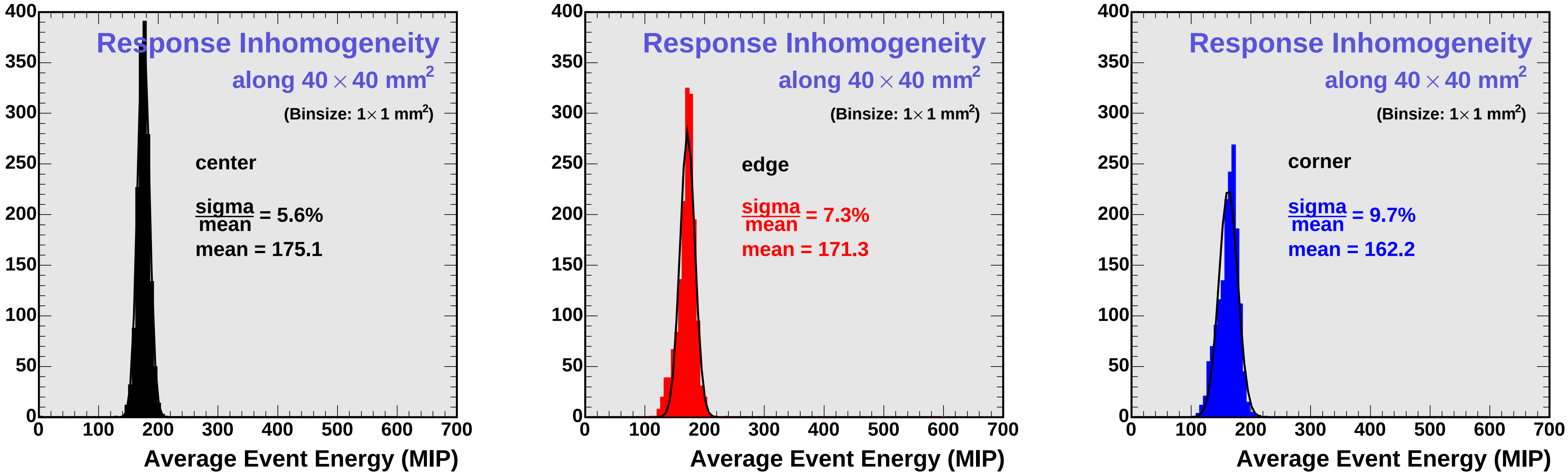
▷ alternate layers staggered along X (by 2.5 mm)

▷ dip is shallower and wider

▷ layers not staggered along Y

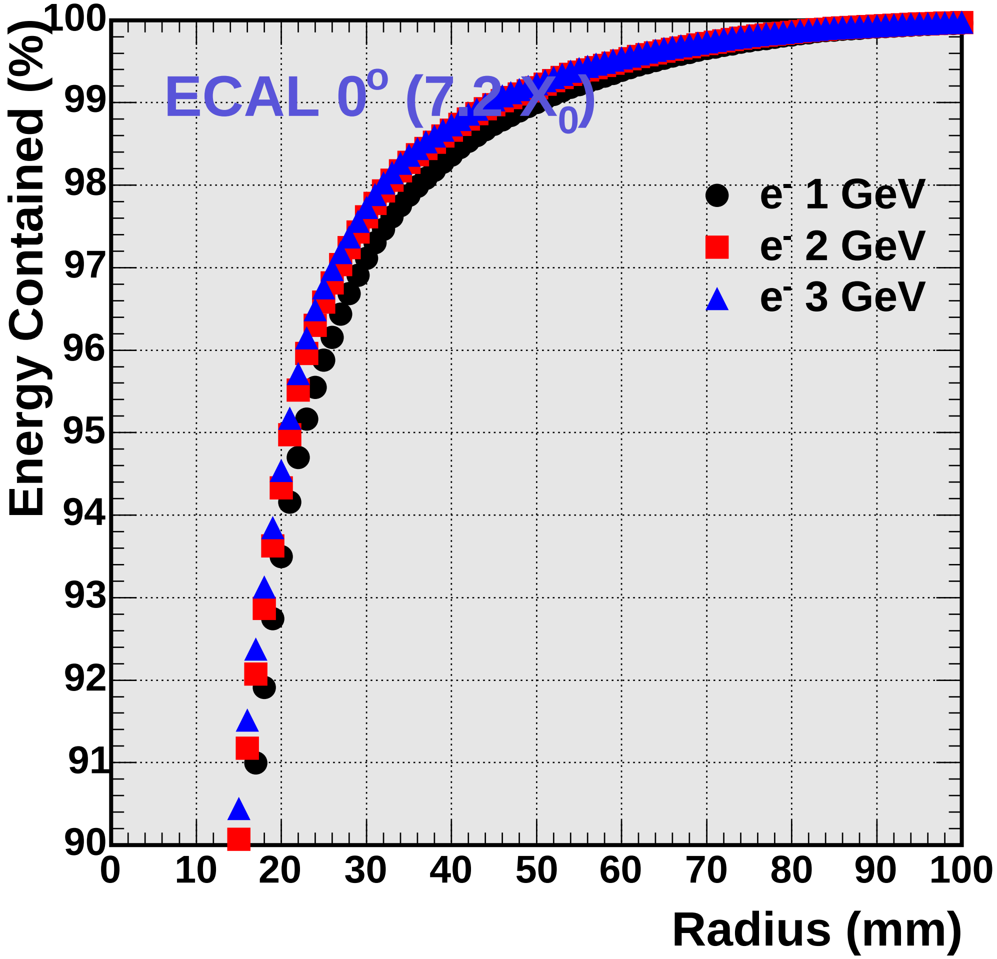
▷ dip is deeper and narrower

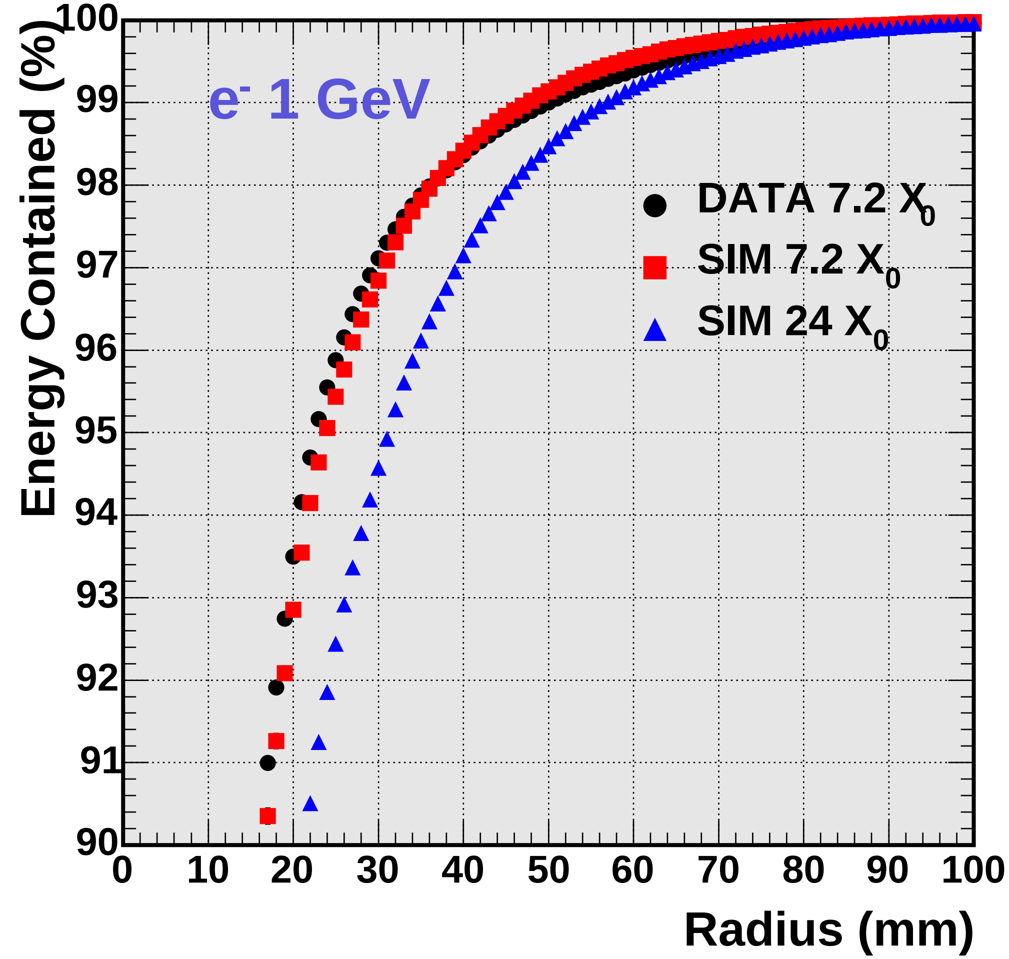
Response Inhomogeneity



▷ **response variation around the center/edge/corner of wafer**

Transverse containment (Moliere radius)





▷ e.g. 1 GeV e^- shower "contained" at

: 90%	within radius	16 mm
: 95%		23 mm
: 99%		50 mm

▷ data-simulation comparison

▷ results expected for the 24 X_0 prototype

REMINDER: for an infinitely long and wide calorimeter

shower contained at	90%	within radius $\sim 1\ R_M$
	95%	$\sim 2\ R_M$
(for solid W, $R_M \simeq 10$ mm)	99%	$\sim 3.5\ R_M$

Reminder (High Granularity Calorimetry)

► . "particle flow paradigm" requires

: 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

: strong interplay between hardware and software

► . CALICE roadmap (concepts+questions $\longrightarrow$ answers and optimal design)

: build ECAL and HCAL prototypes and do extensive individual and combined testbeam studies

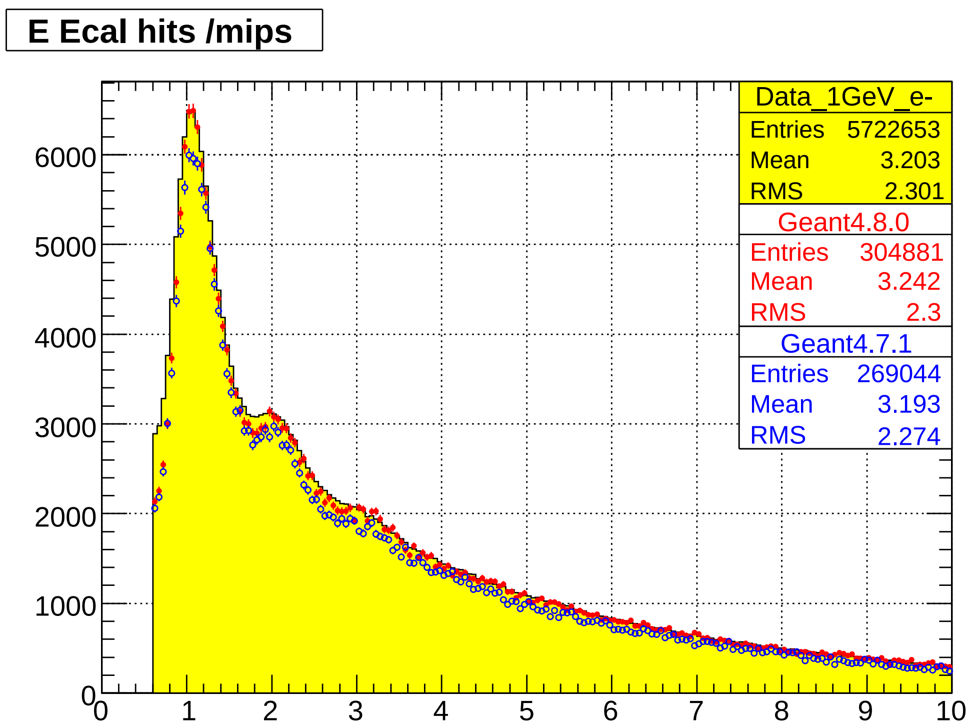
: demonstrate proof of technology/detector concept(s)

: debug-characterise-optimise detector performance

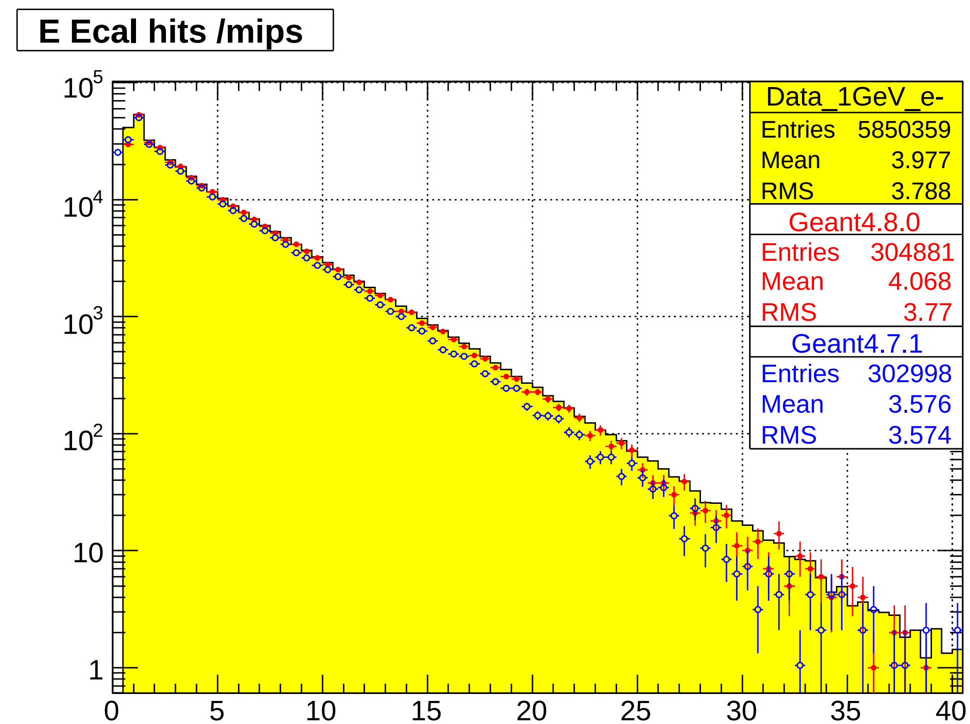
: test-validate-improve simulation codes and shower packages

Data-simulation comparison (energy per hit)

(studies by D.Ward)



#of hits vs hit energy(mip)

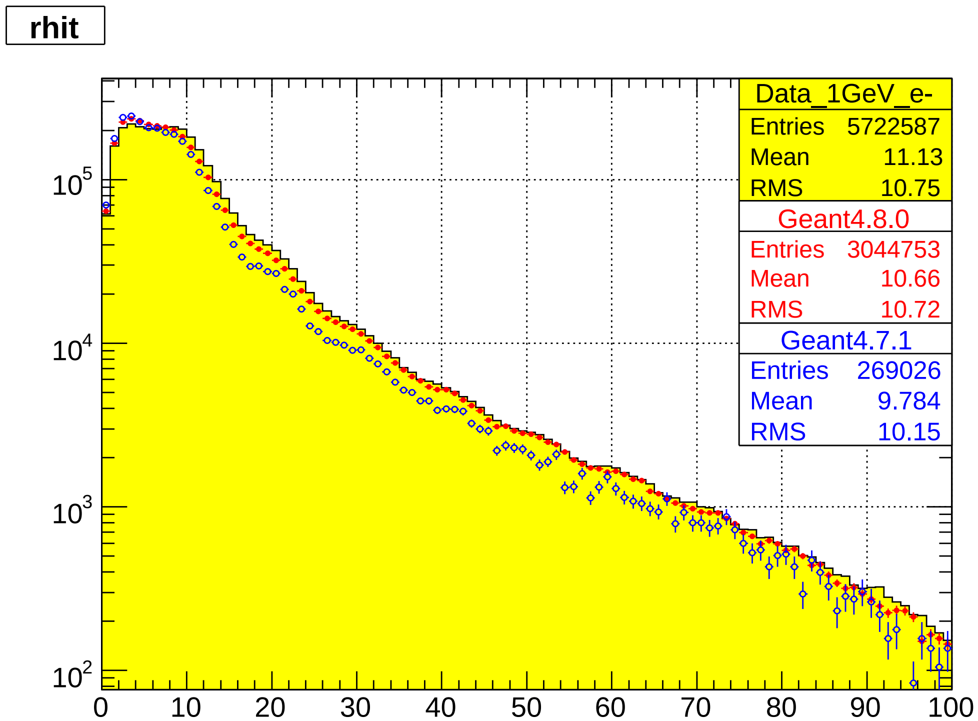


#of hits vs hit energy(mip)

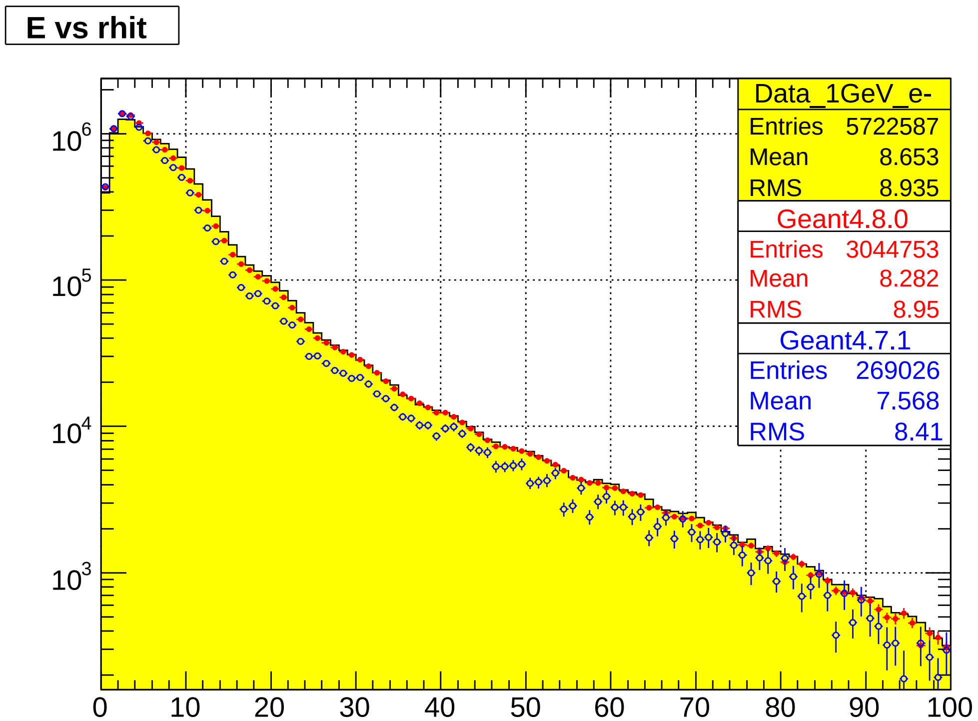
- ▷ **good agreement between data and simulation**
- ▷ **G4.8.0 improved wrt G4.7.1**

Data-simulation comparison (shower profile)

(studies by D.Ward)



#of hits vs distance(mm) from shower barycenter



energy vs distance(mm) from shower barycenter

- ▷ **good agreement between data and simulation**
- ▷ **G4.8.0 improved wrt G4.7.1**

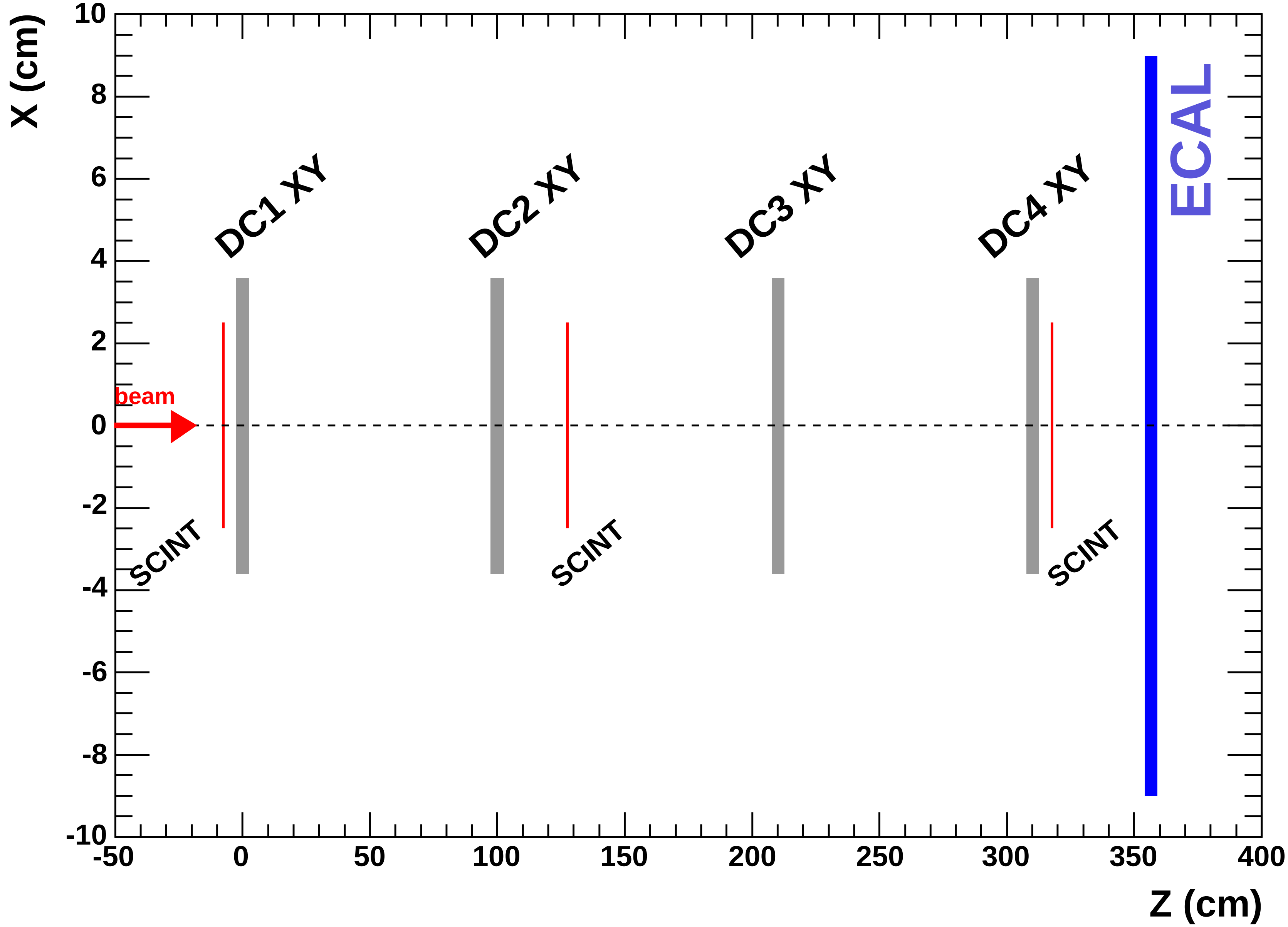
Summary

- **"1/3" of CALICE Si/W ECAL prototype**
  - 3024 channels of 1 $\times$ 1 cm^2, 7.2 X_0, 14 layers
  - first testbeam at DESY with e^- (Jan/Feb05)
  - results shown from studies on
    - ▷ position resolution, tracking performance
    - ▷ response map, inhomogeneity
    - ▷ transverse containment, Moliere radius
  - further data analysis in progress

- **next steps**
  - testbeams at DESY and at CERN with ECAL completed and in combination with HCAL
  - see also talks from G.Gaycken(ECAL) and F.Sefkow(HCAL)

BACKUP SLIDES

Testbeam layout



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.

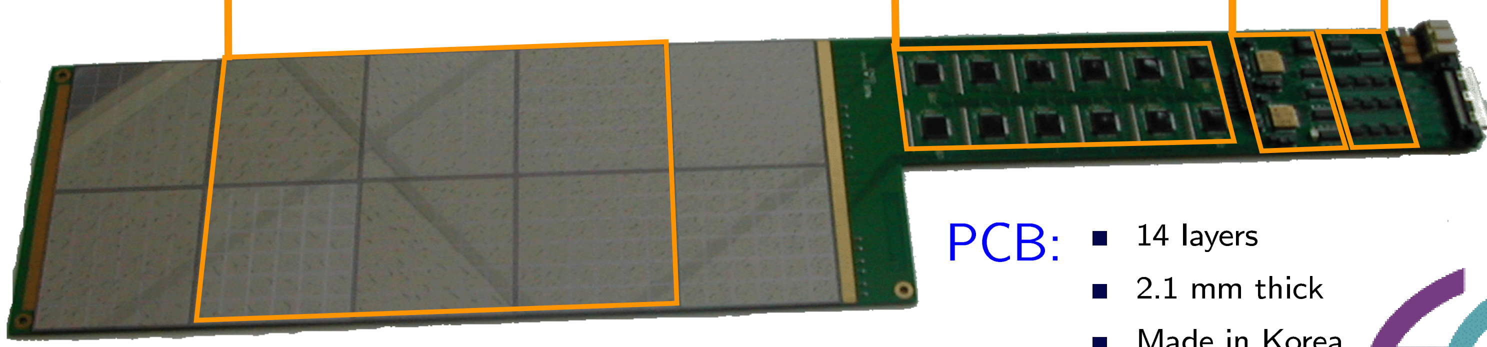
Front-End chip

12 FLC_PHY3 front-end chip

- 18 channels / chip
- 13 bit dynamic range

Line buffers

- To DAQ part
- Differential.



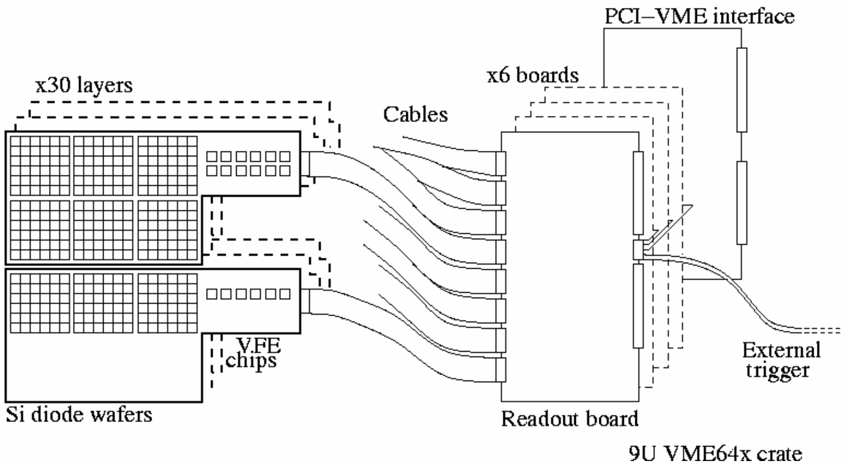
PCB:

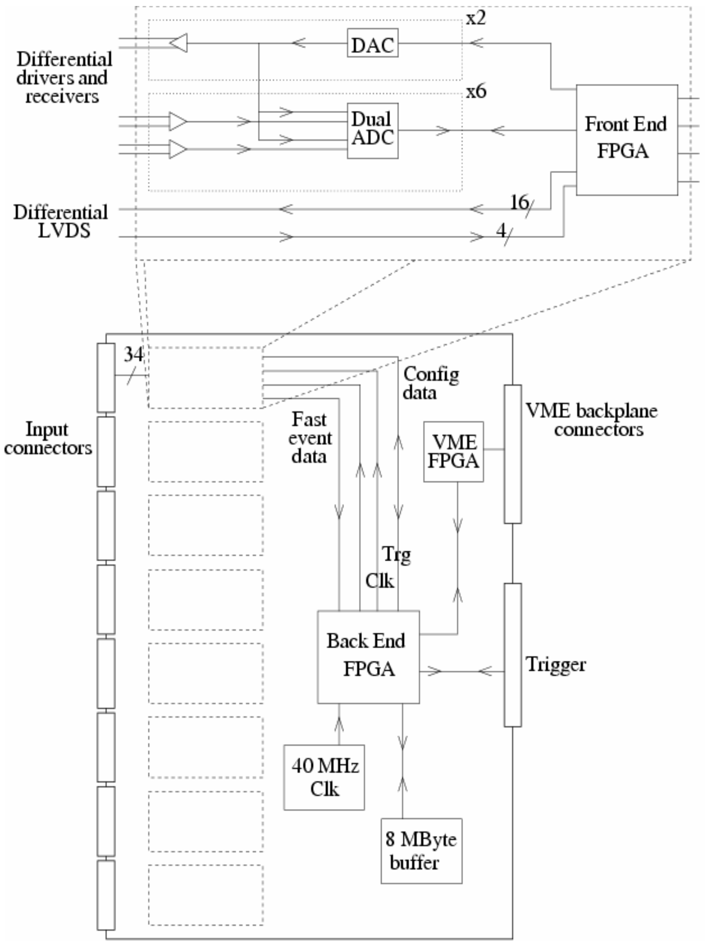
- 14 layers
- 2.1 mm thick
- Made in Korea

(G.Gaycken)

CALICE readout card

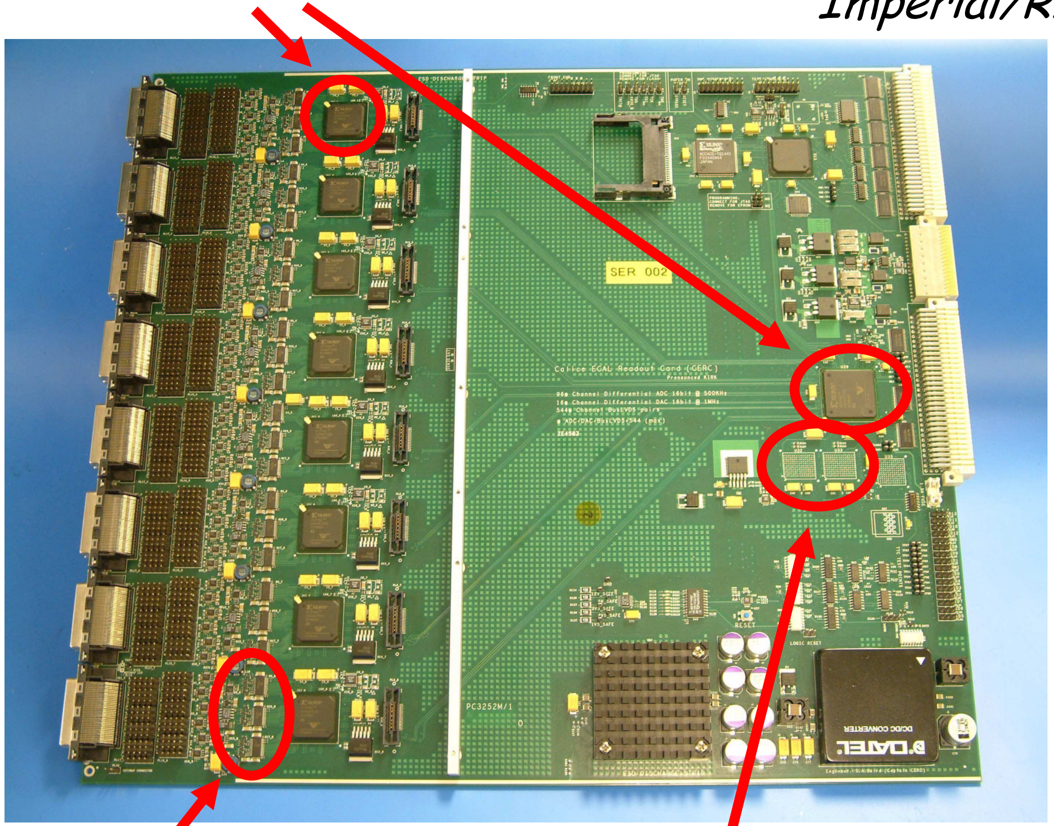
- Calice Readout Card (CRC) VME board
  - Modified CMS silicon tracker readout board
  - Does VFE PCB control, digitisation and data buffering
  - Also does trigger control





Virtex-II FPGAs

Imperial/RAL/UCL



16-bit dual ADCs

8MByte buffer

(P.Dauncey)

General

- ► . **particle flow paradigm**

  : 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

- ► . **CALICE ECAL(Si/W) and HCAL(Scint/Fe, RPC/Fe) prototype studies**

  : debug technology/detector concept(s)

  : detector characterisation

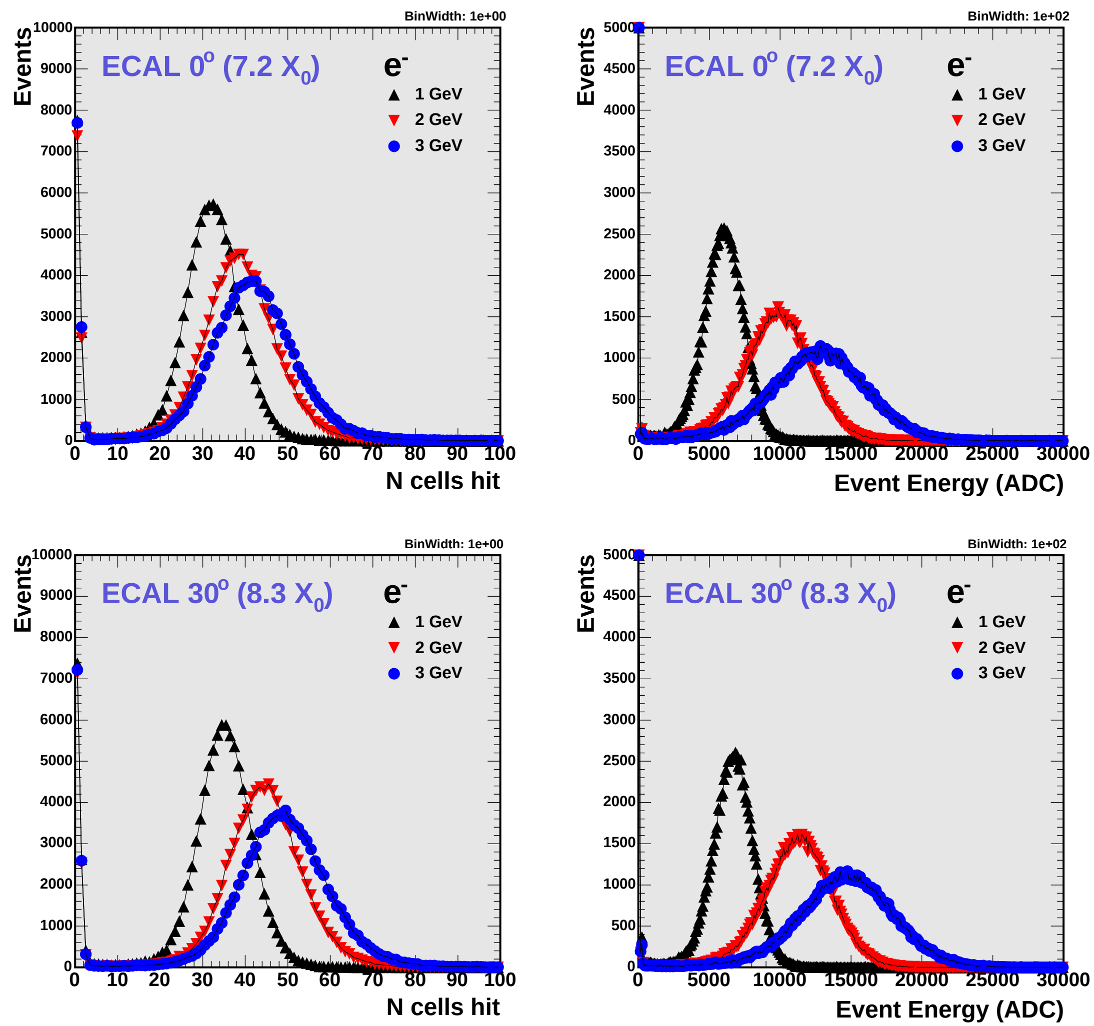
  : test "particle flow paradigm", interplay between hard/soft-ware

  : test-validate-improve simulation codes and shower packages

- ► . details about CALICE Si/W ECAL protoype follow

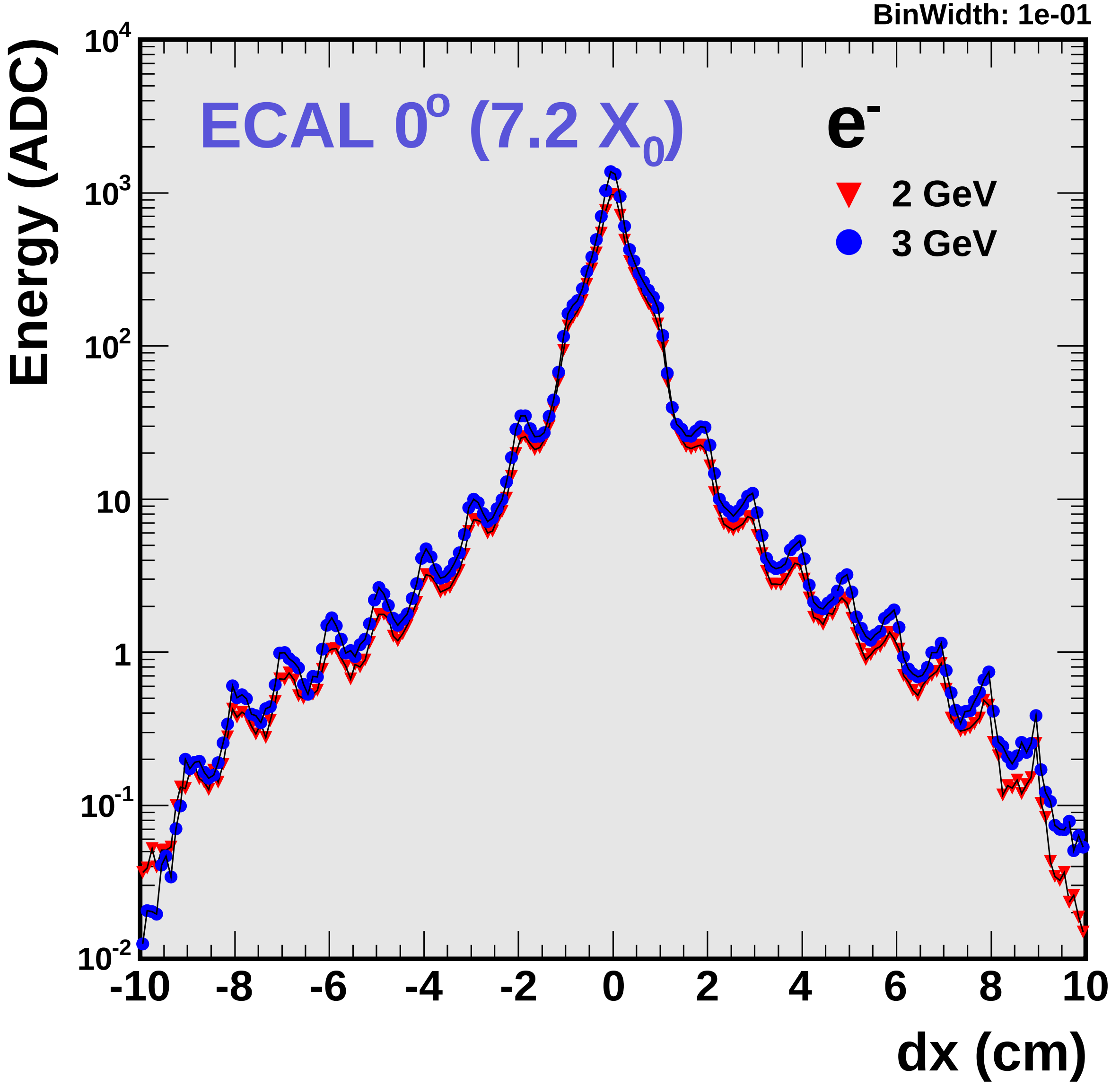
"Response" to electrons

N cells hit **E deposited**



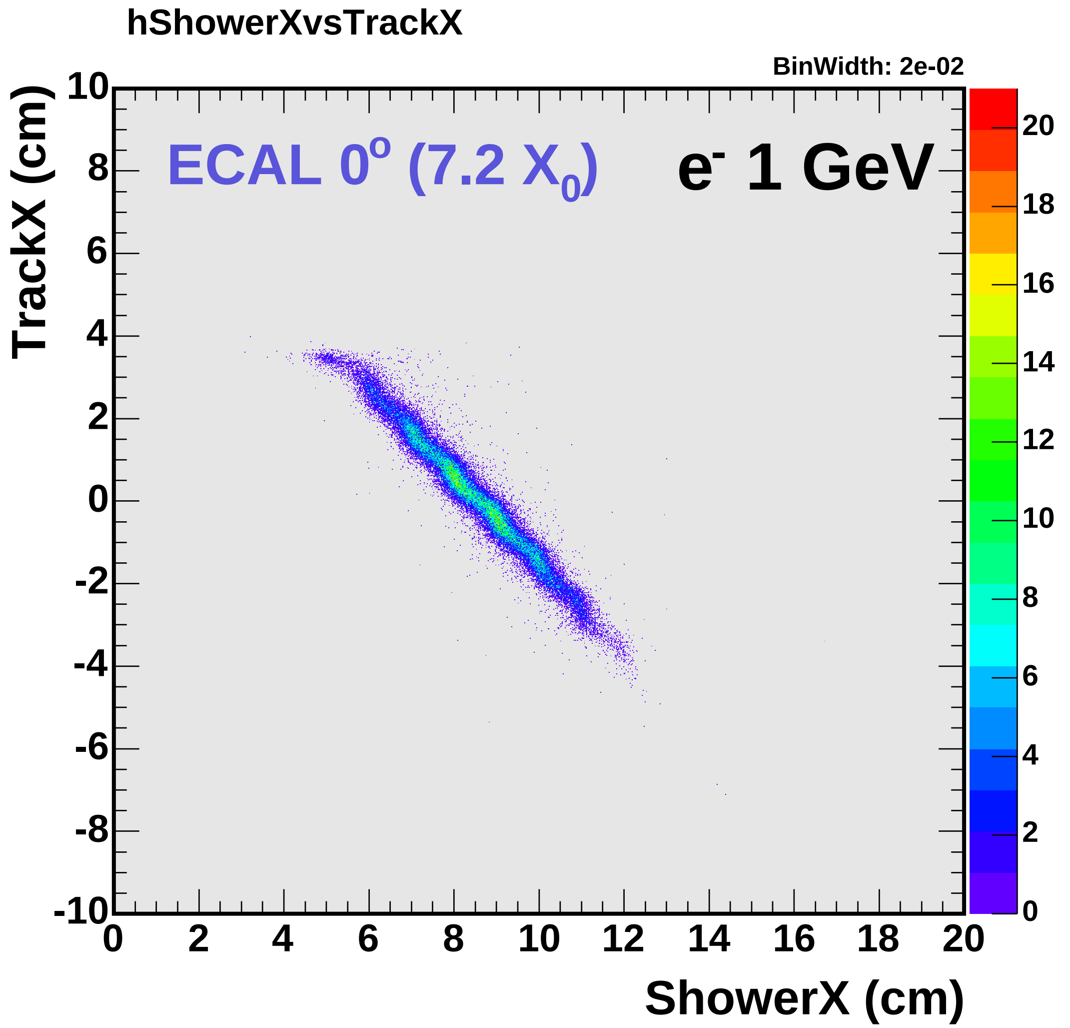
- ▷ **no weighting, no event selection, no tracking**
- ▷ **showers better contained at 30°**

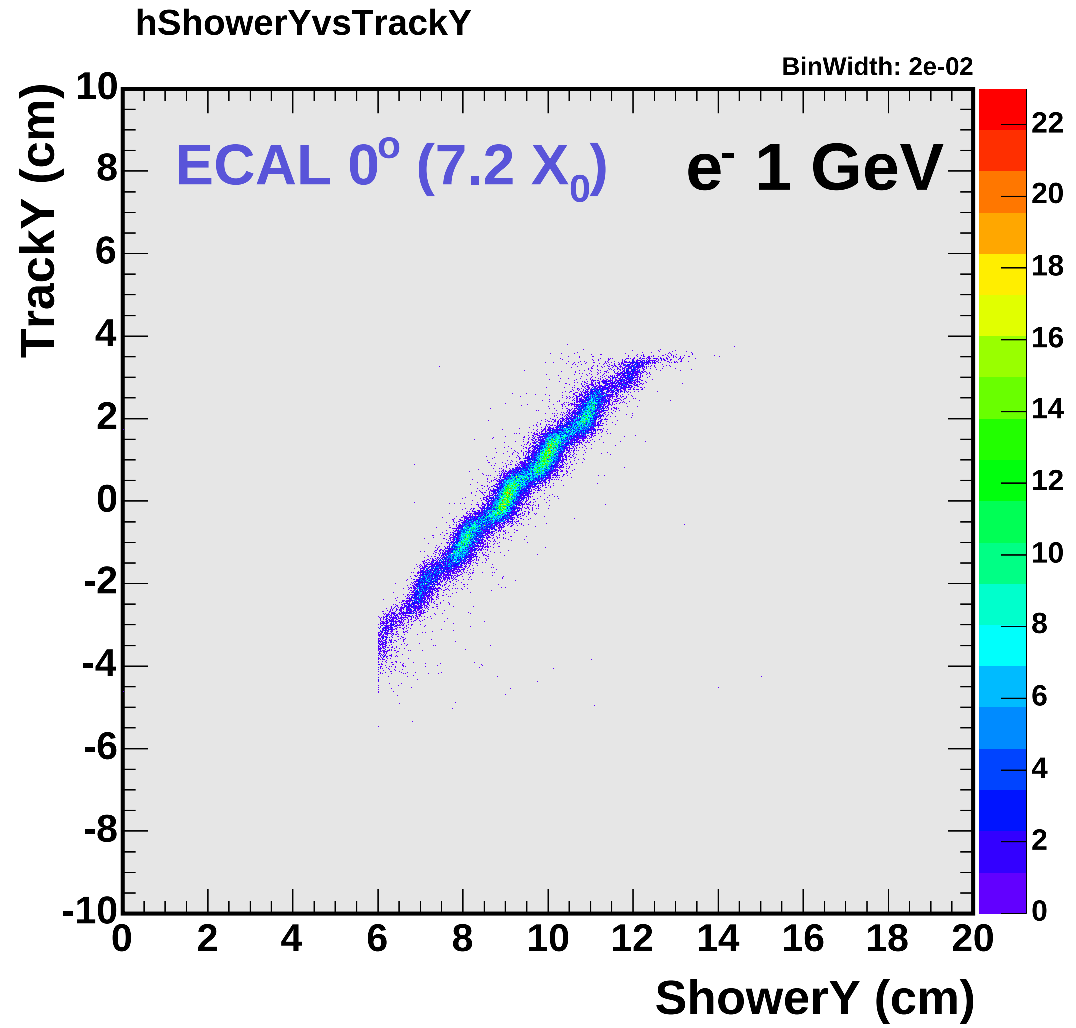
Transverse tomography



- no weighting, no event selection, no tracking
- dx = CellX - BarycenterX
- distance between peaks = 1 cm = transverse granularity

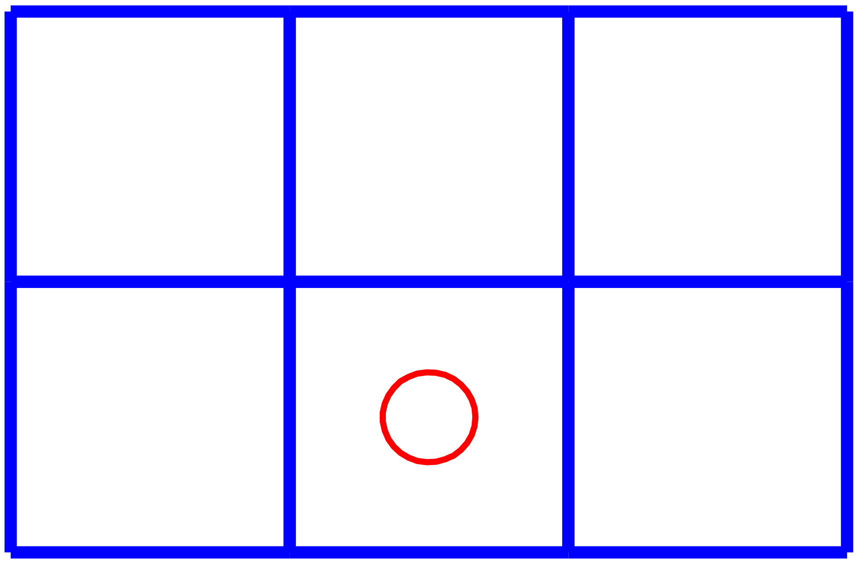
Position scan

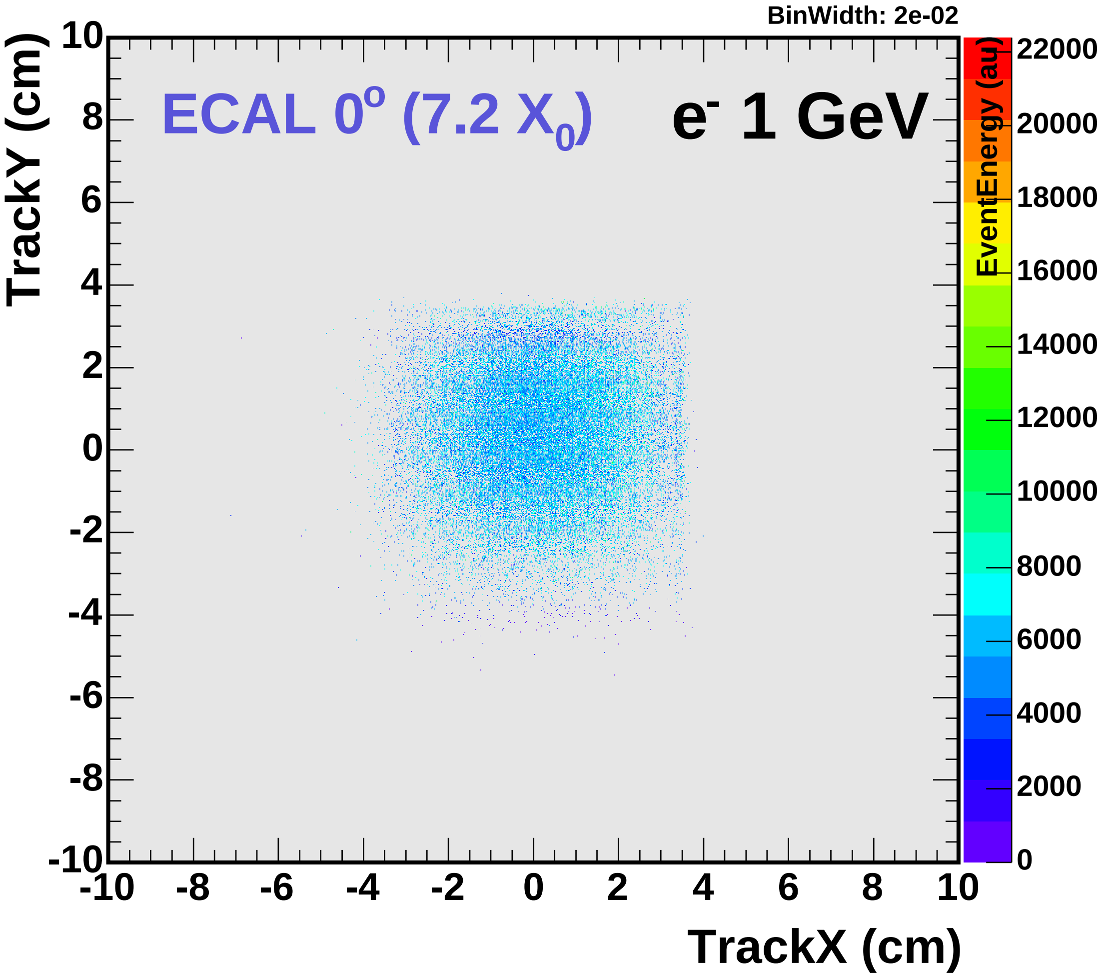




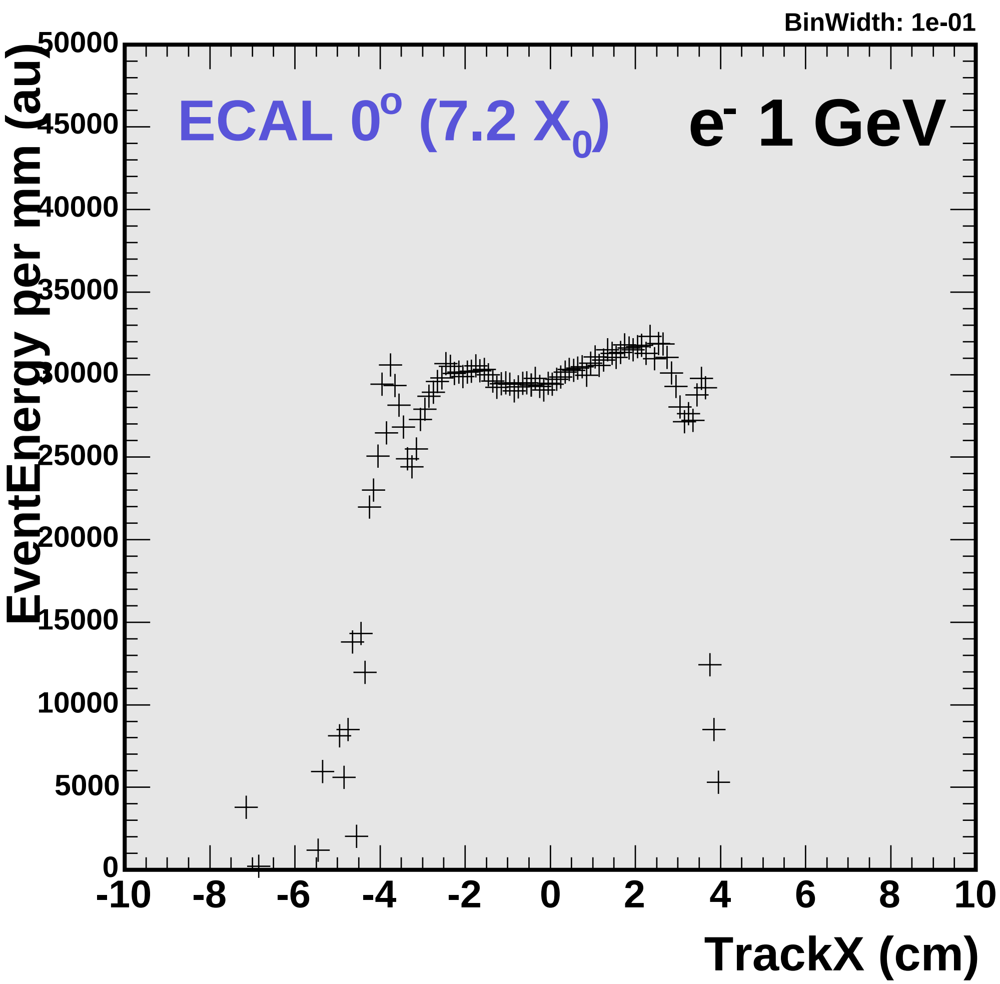
- ShowerX,Y from barycenter in ecal
- TrackX,Y from 4 drift chambers

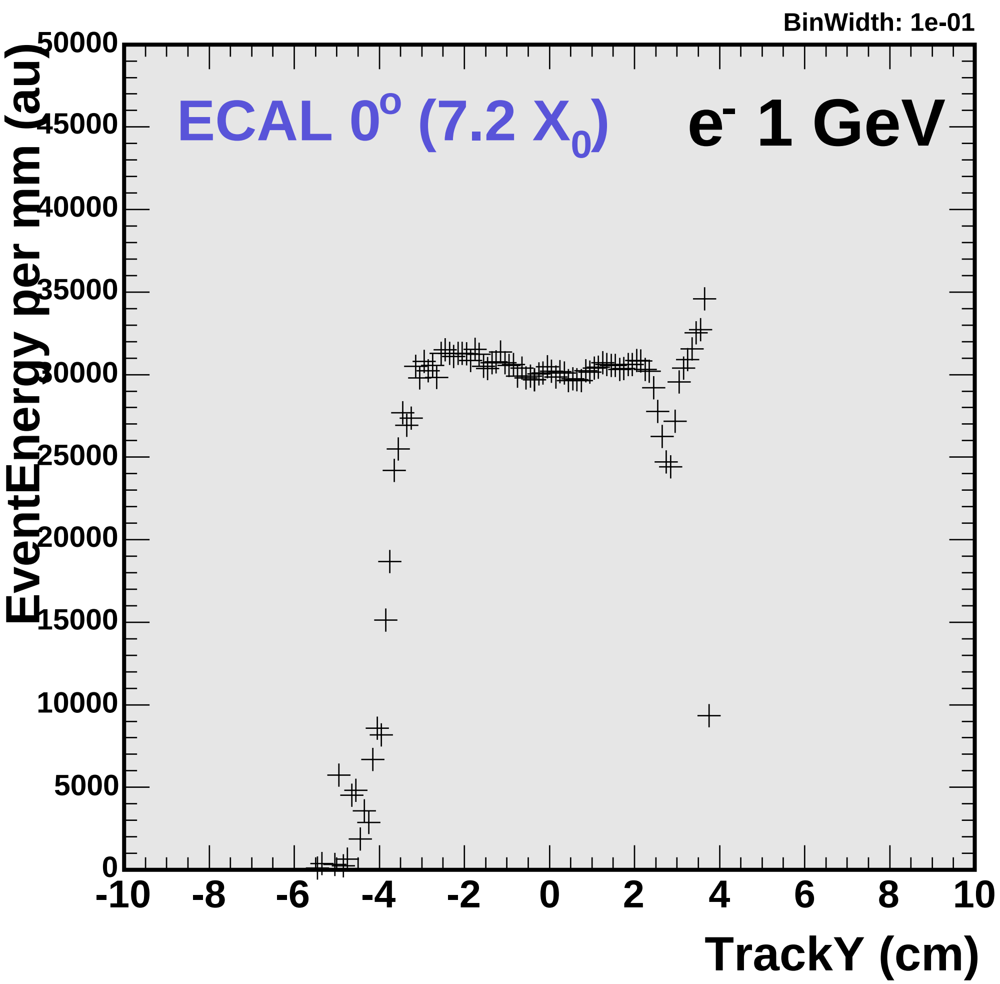
Position scan - center of wafer





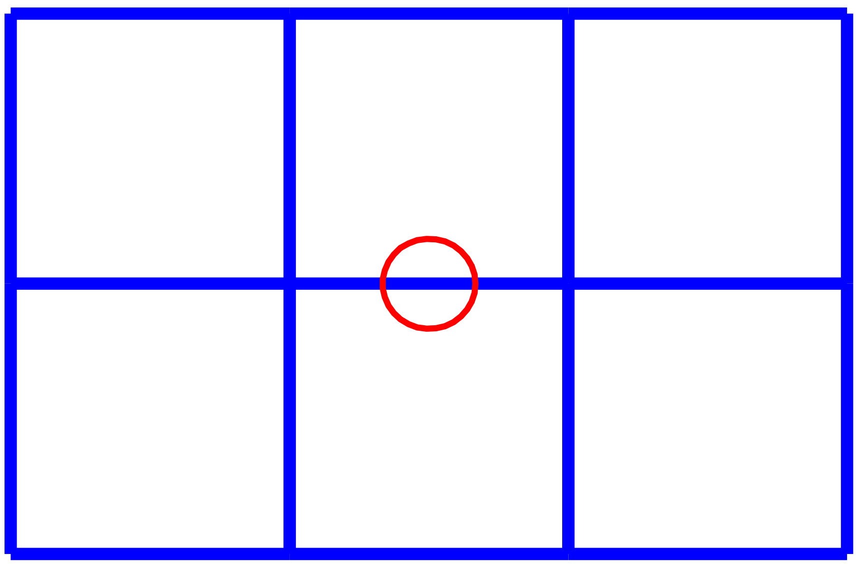
Position scan - center of wafer

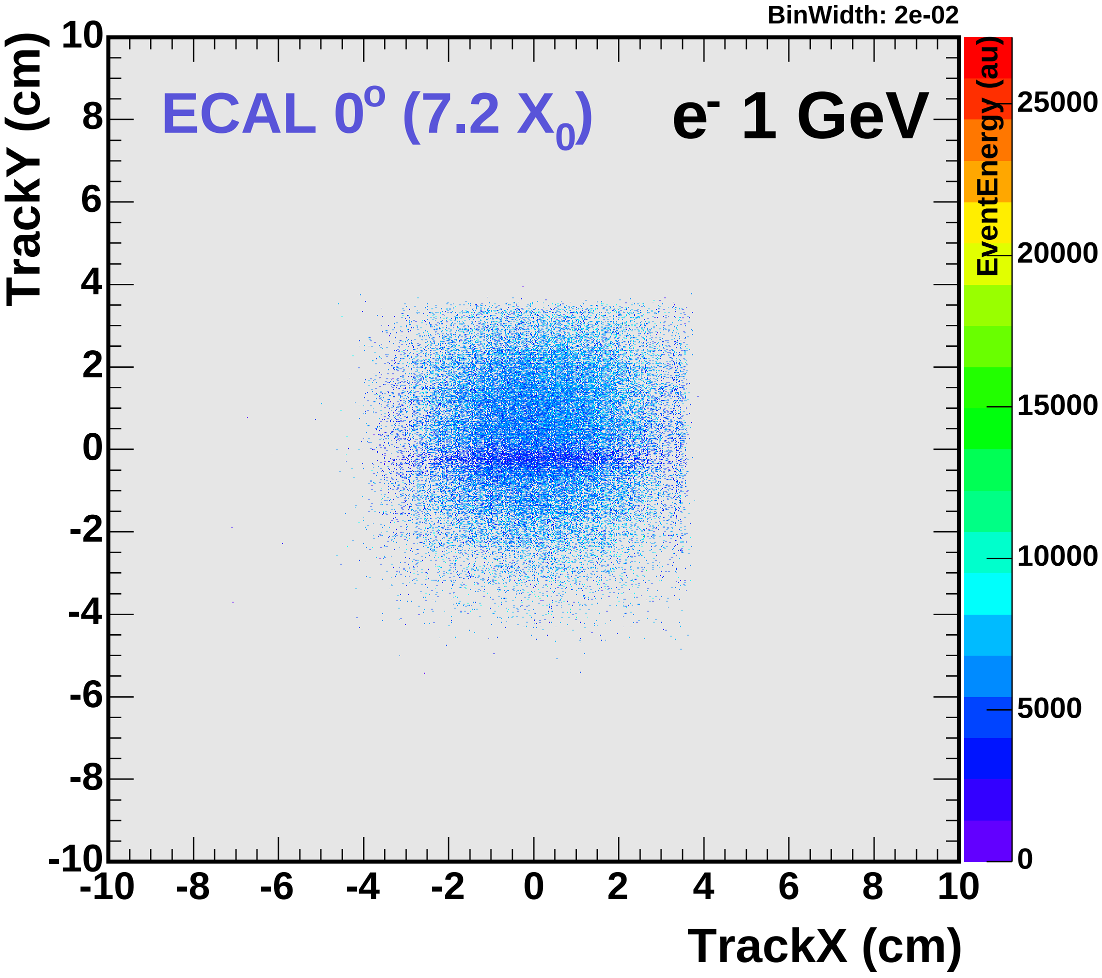




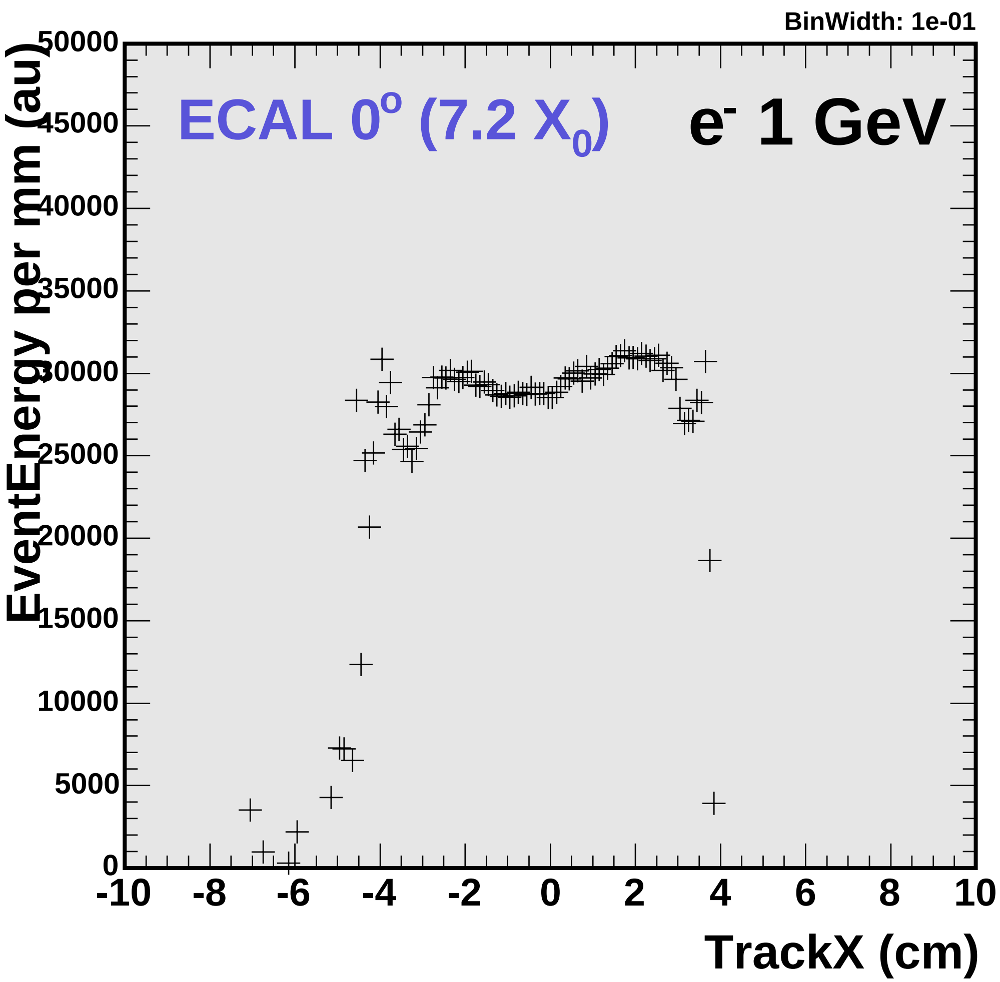
▷ PRELIMINARY

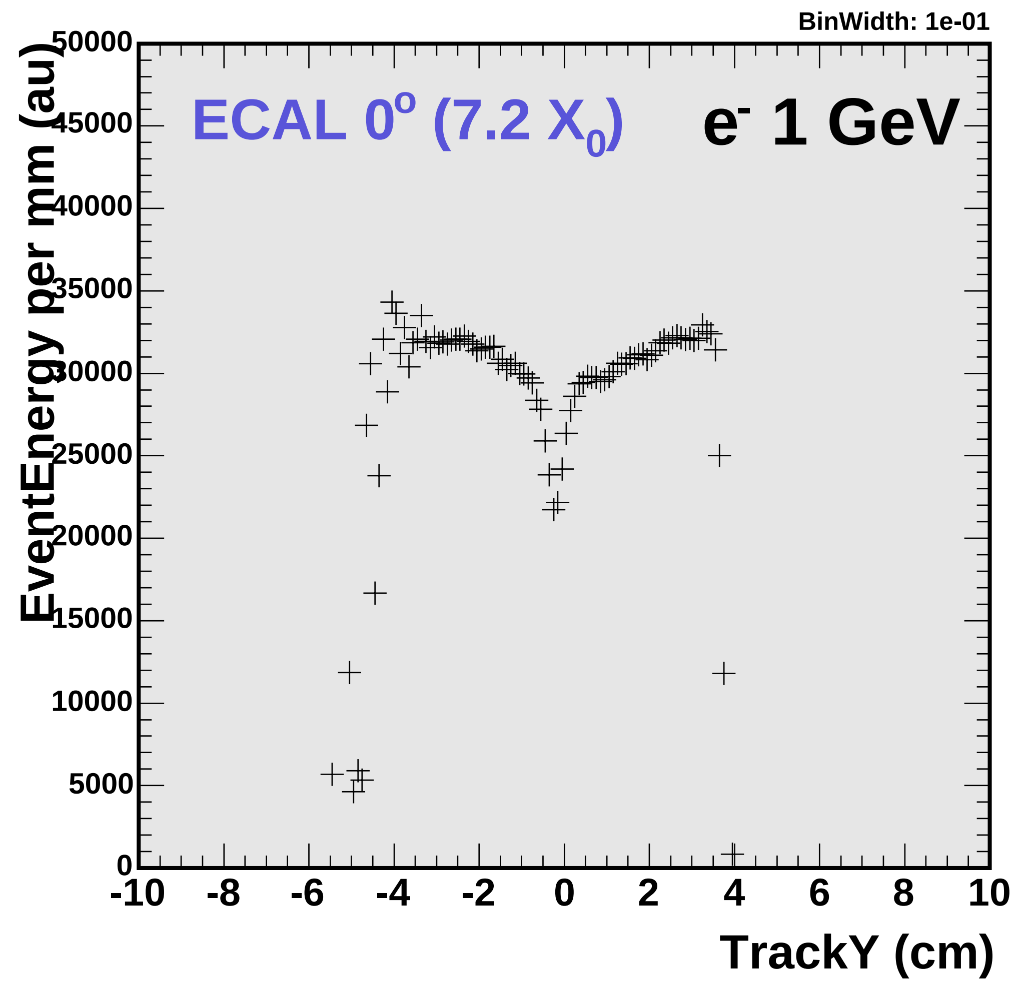
Position scan - edge of wafer





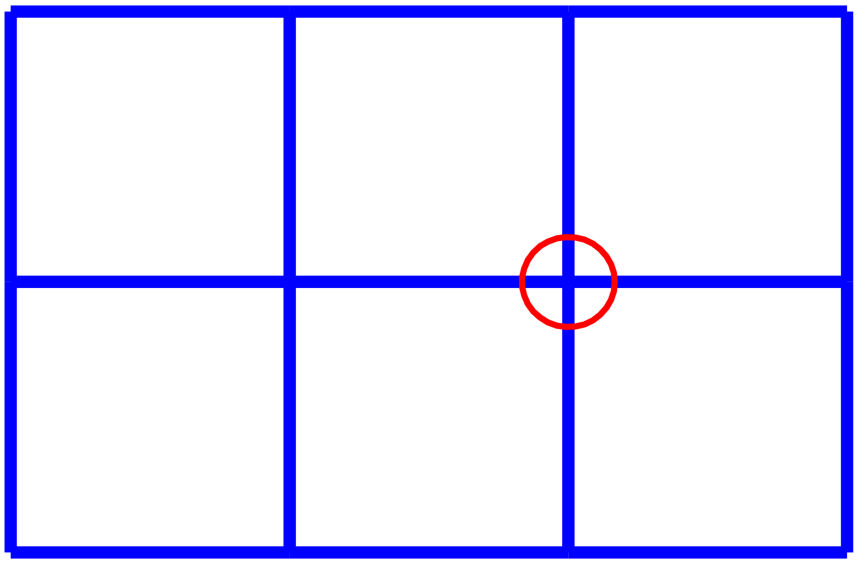
Position scan - edge of wafer

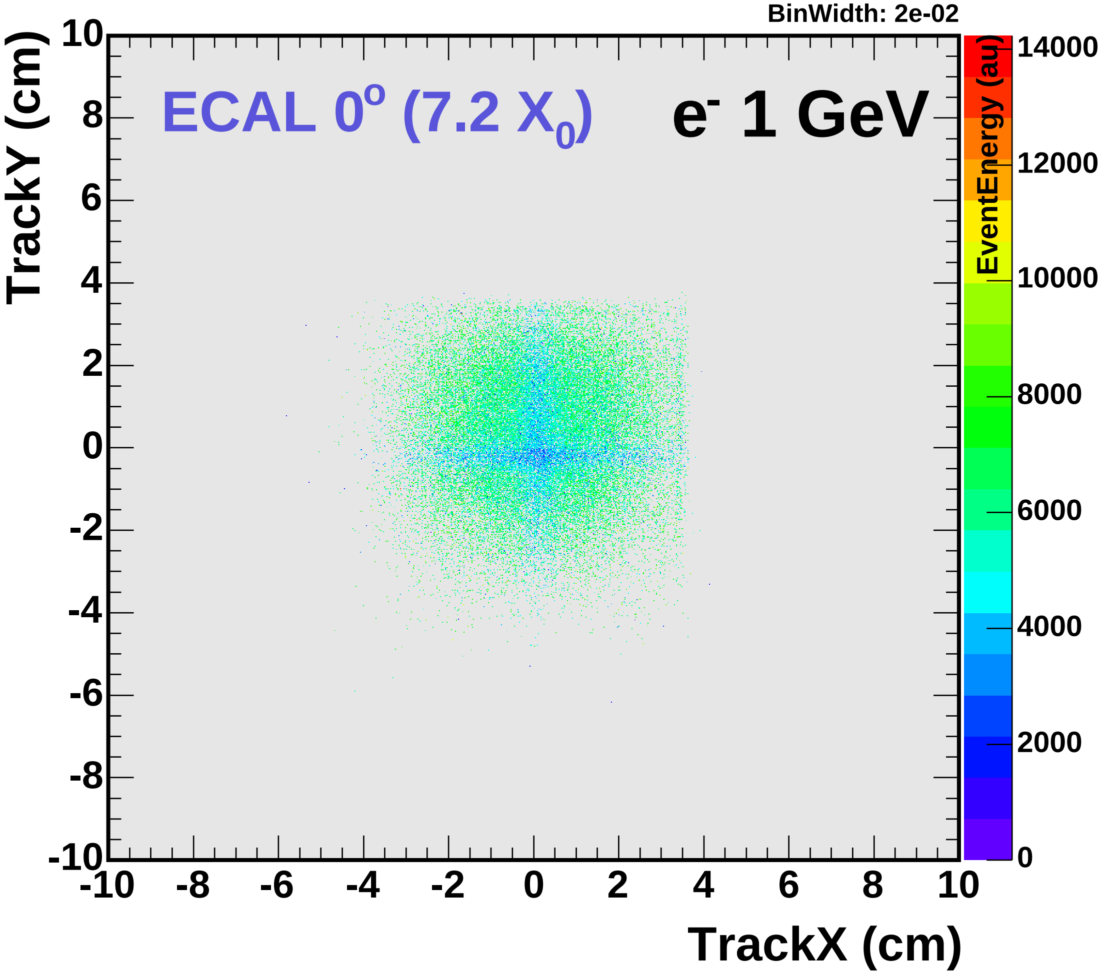




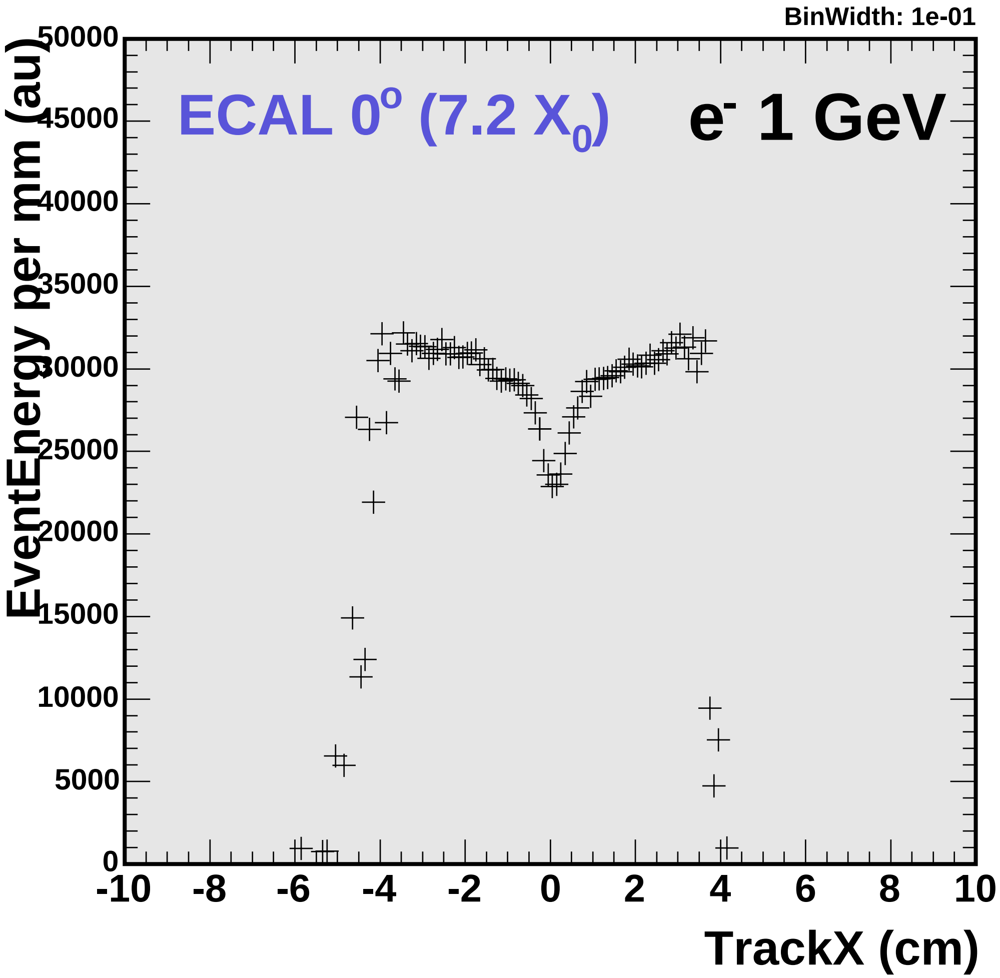
▷ PRELIMINARY

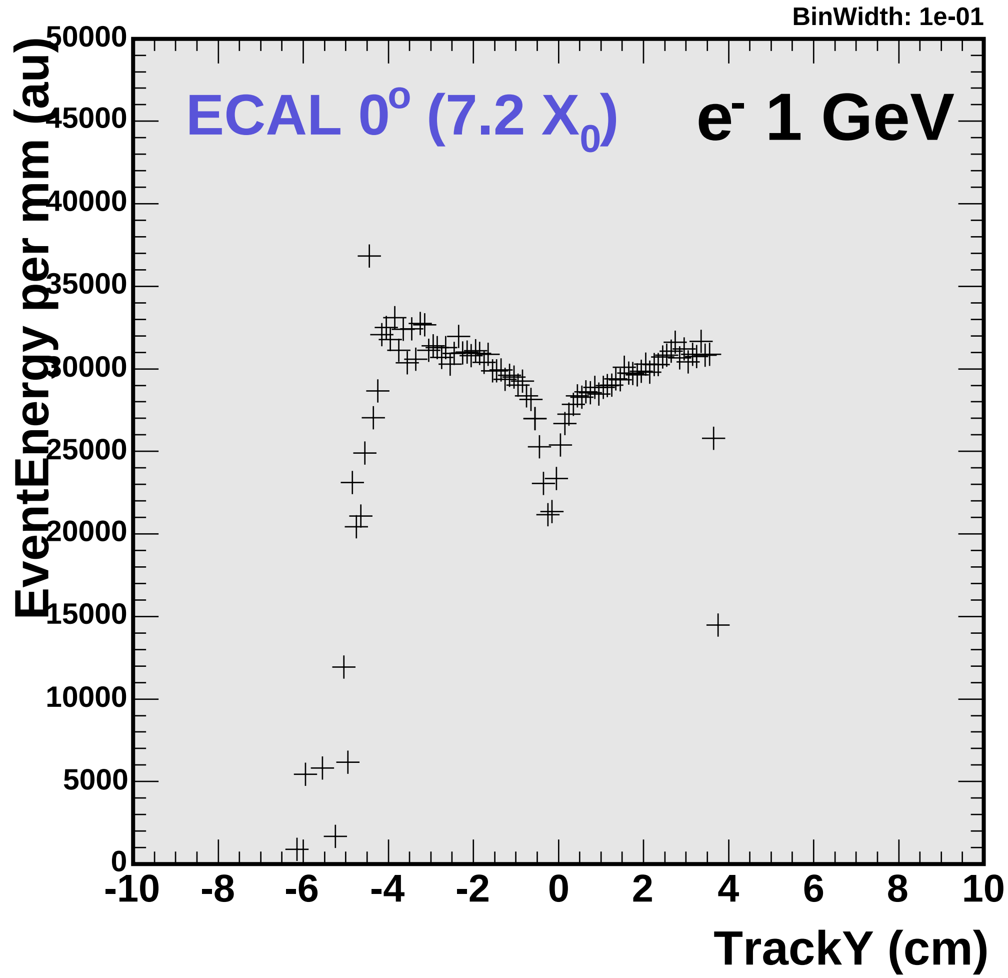
Position scan - corner of wafer





Position scan - corner of wafer



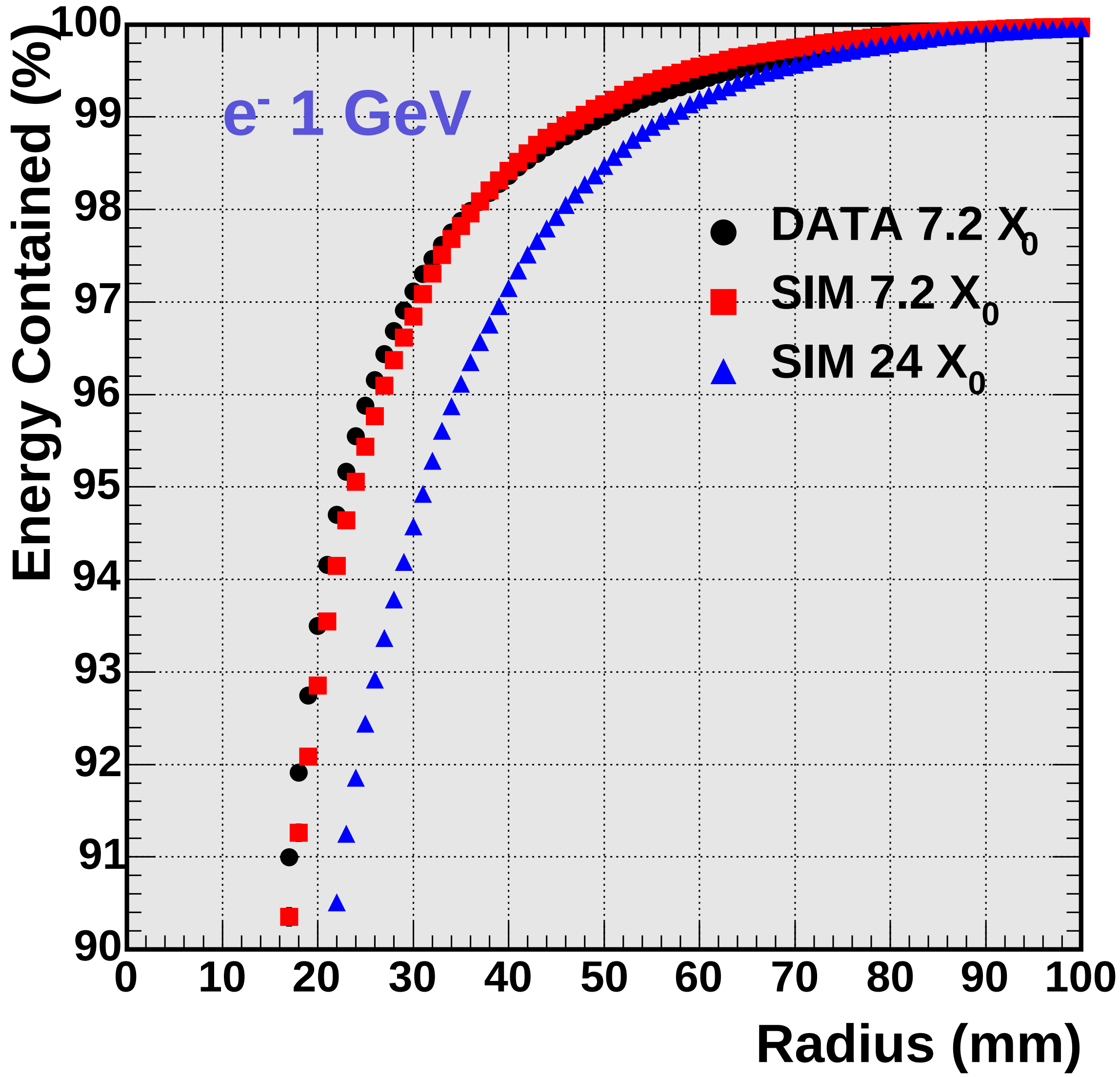


- ▷ alternate layers staggered along X
- ▷ dip is shallower and wider

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

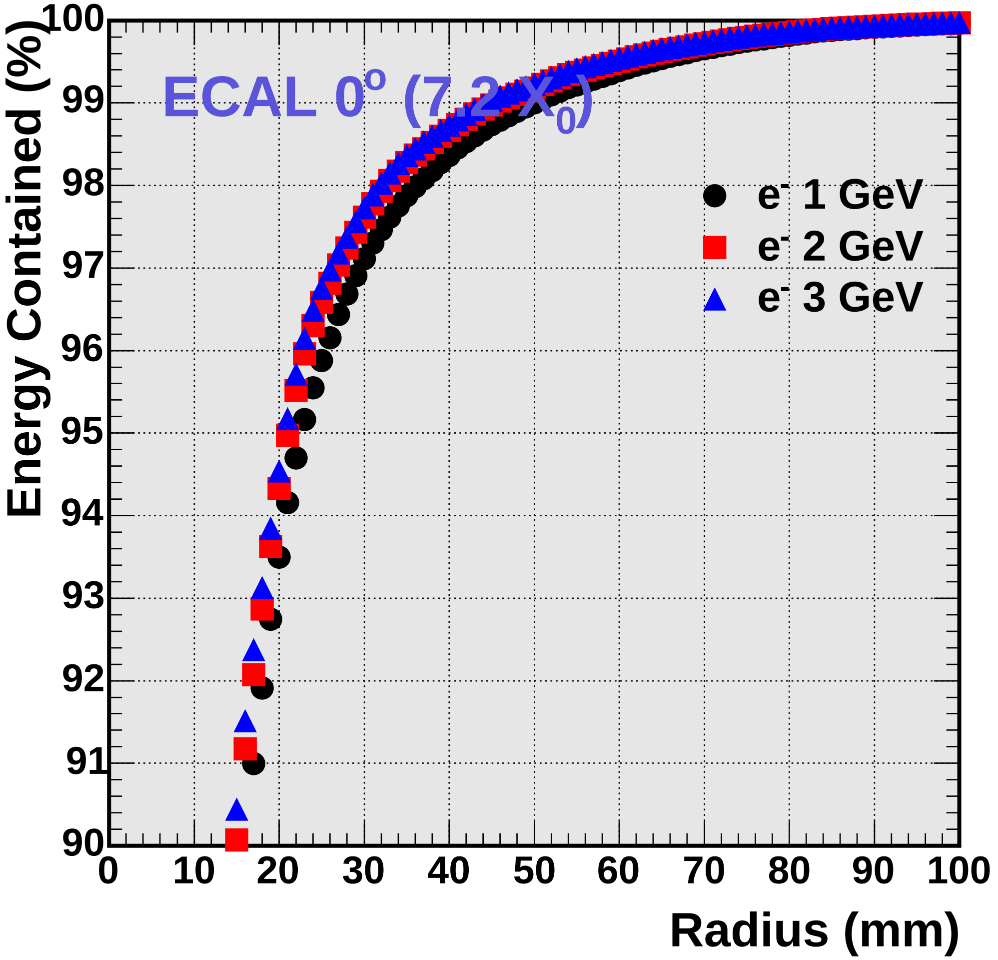
▷ **PRELIMINARY**

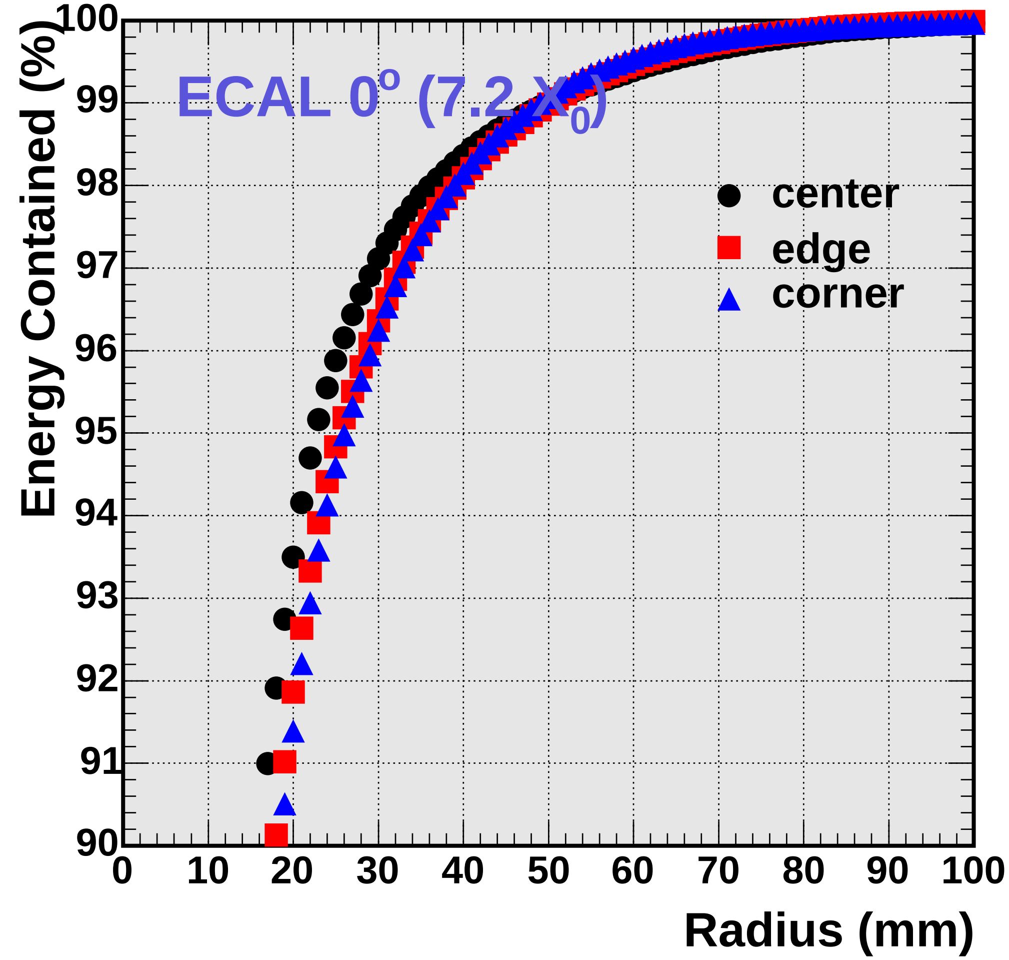
Transverse containment (Moliere radius)



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

Transverse containment (Moliere radius)





▷ **e.g. 1 GeV e^- shower "contained" at**

- **: 90% within radius 16 mm**
- **: 95% 23 mm**
- **: 99% 50 mm**

▷ **slight degradation if impact is along edge/corner of wafer**

REMINDER:	for an infinitely long and wide calorimeter		
	shower contained at	90%	within radius $\sim 1\ R_M$
		95%	$\sim 2\ R_M$
	(for solid W, $R_M \simeq 10$ mm)	99%	$\sim 3.5\ R_M$