# Electromagnetic Calorimetry for ILC

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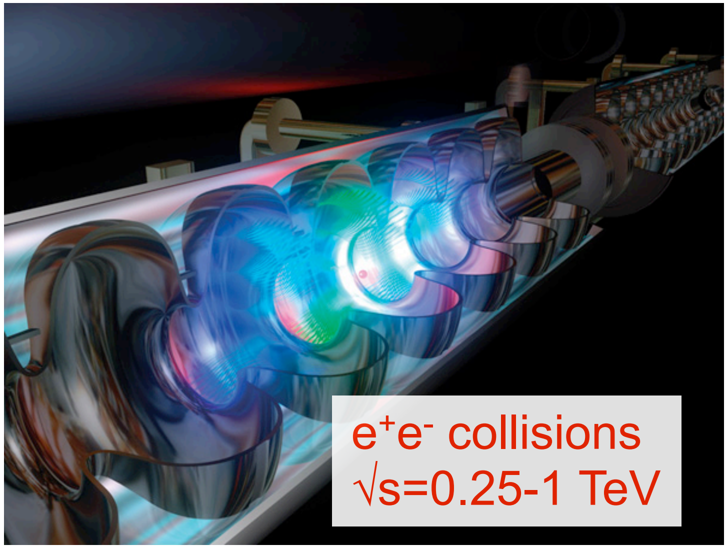
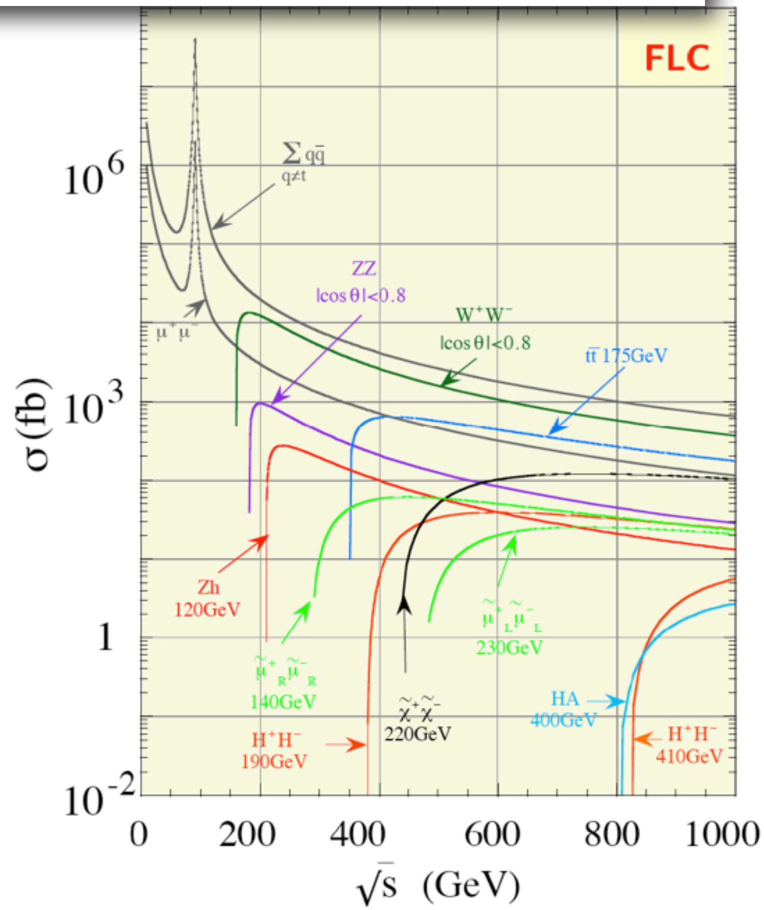
LPC Clermont Ferrand / IN2P3 / CNRS

CALICE
Calorimeter for ILC

M. Battaglia et al. hep-ex/060301v1




- clean environment
- small xsections
- reconstruct ALL final states




@ 500 GeV
$500fb^{-1}$/year

$W^{\pm}\nu e$ (30M)
$W^+W^-$(1.M)
$t\bar{t}$(250k)
ZZ(75k)
hZ(30k 120 GeV)

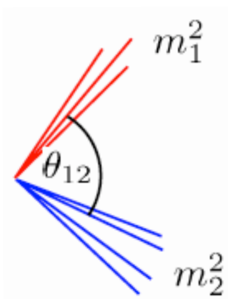
need precise/ efficient boson tagging

| Z to | BR |
|---|---|
| $\ell^+ \ell^-$ | 10% |
| qq (jets) | 70% |

| W to | BR |
|---|---|
| $\ell^{\pm} \nu$ | 32% |
| qq' (jets) | 68% |

| H(120,SM) to | BR |
|---|---|
| $\ell^+ \ell^-$ | <15% |
| qq(jets) ,WW,ZZ | >85% |

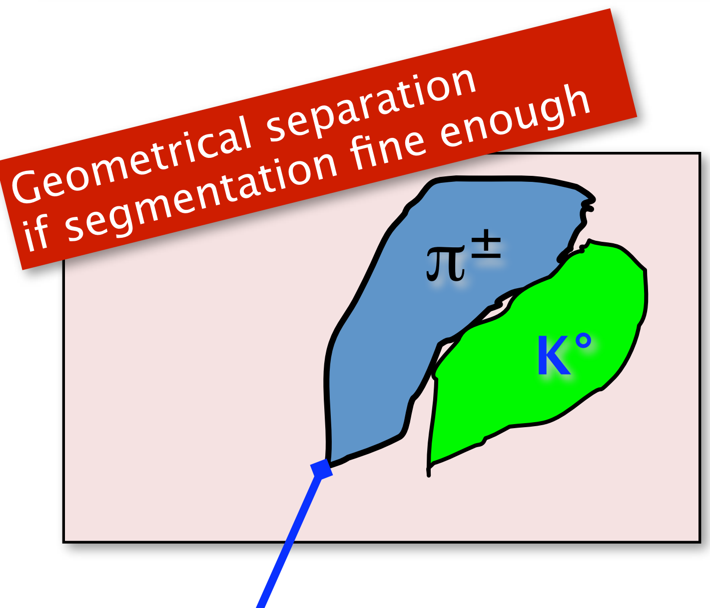
## Separate W and Z di-jet decays




$$\frac{\sigma_m}{m} \approx \frac{\Gamma_Z}{m_Z} \approx \frac{\Gamma_W}{m_W} \approx 0.027$$

**~ 2.75σ separation between W and Z peaks if $\sigma_{E_j} / E_j < 3.8\ \%$**

## Particle Flow Algorithm



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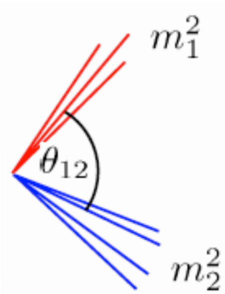


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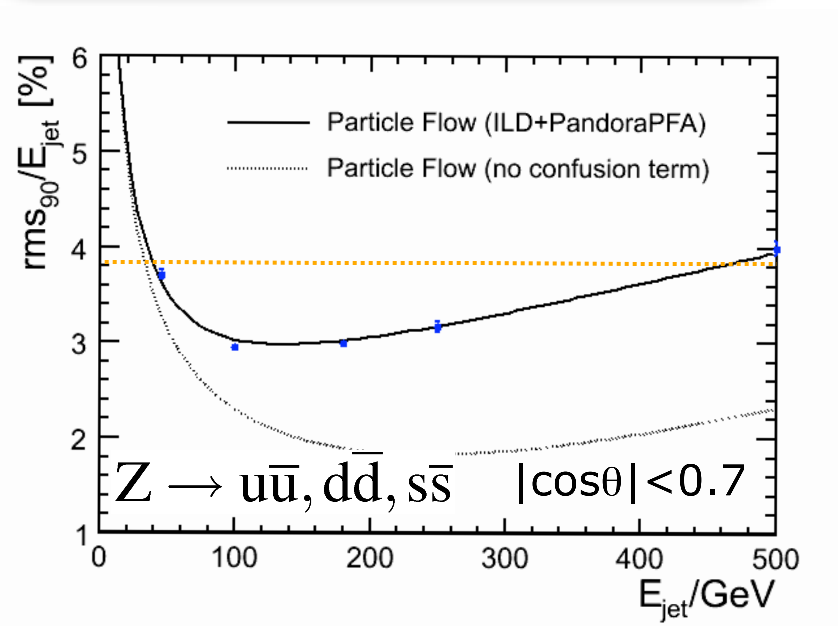
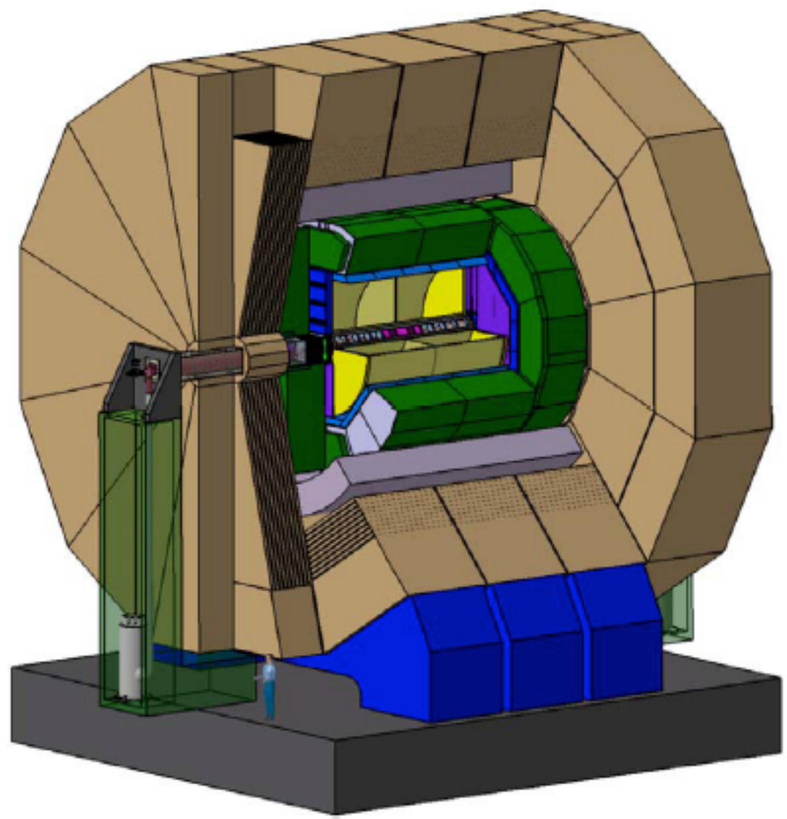


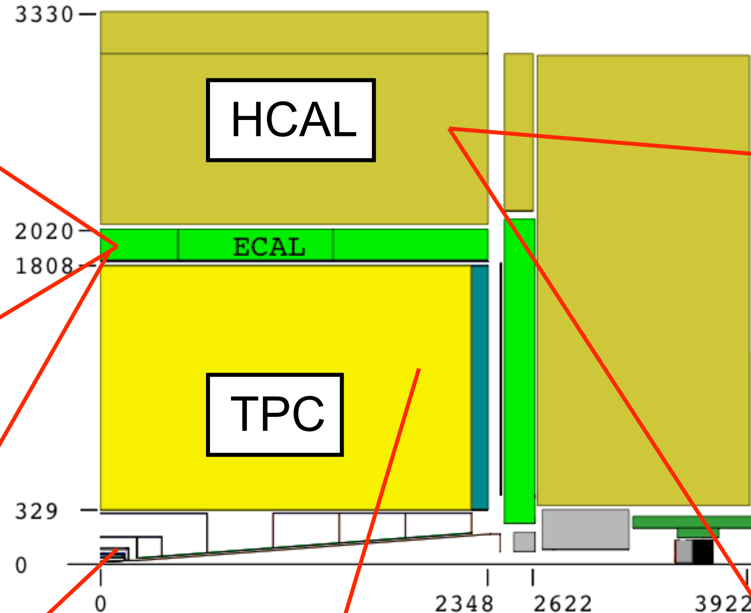
# ILD detector (LOI, March 09)

## ECAL

★ SiW: 5×5 mm²

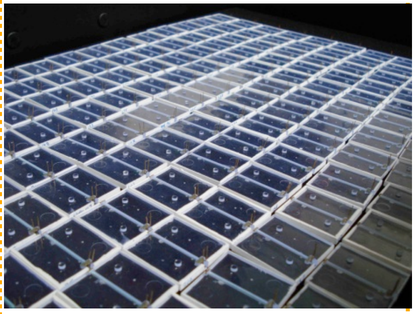
★ ScintW: 10x10 mm²

★ MAPS: 50x50 μm²

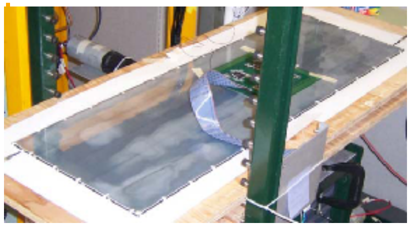



## HCAL

★ Steel Scint.
Analogue
3x3 cm2 tiles

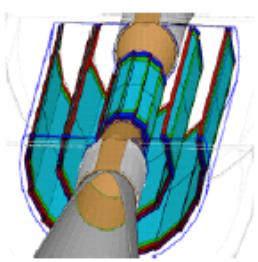


★ Steel RPC
(Semi) Digital
1x1 cm2

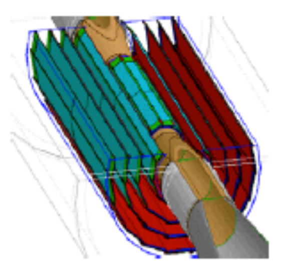


## Vertex Detector

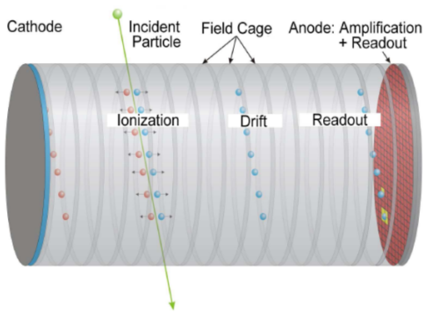
★ 3 Double Layers



★ 5 Single Layers



## TPC



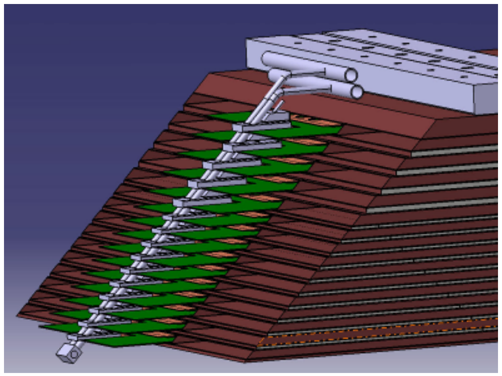

★MPCD
Readout

★Digital
★Analog

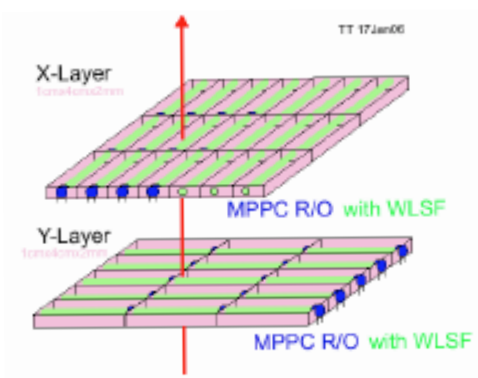
# Calorimeters for ILC (CALICE)

## ECAL

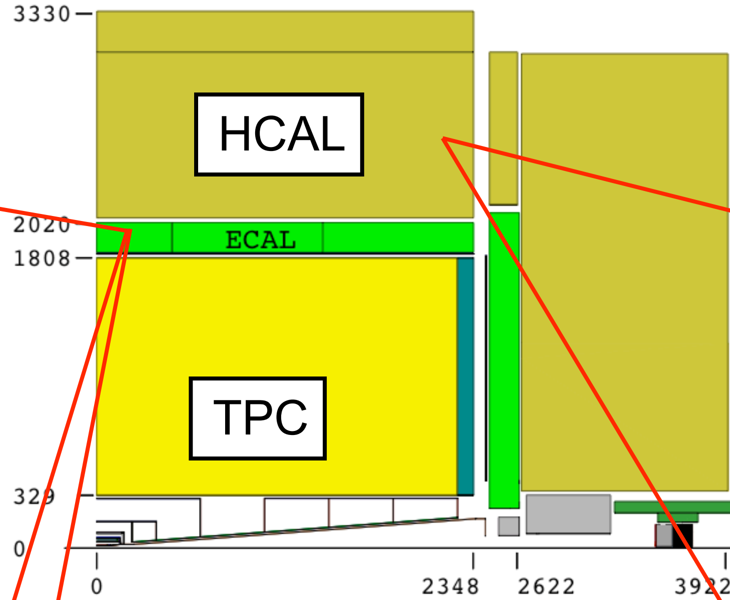
★ SiW: 5×5 mm$^2$



★ ScintW: 10x10 mm$^2$




★ MAPS: 50x50 μm$^2$

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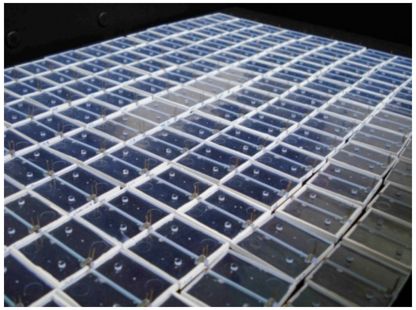
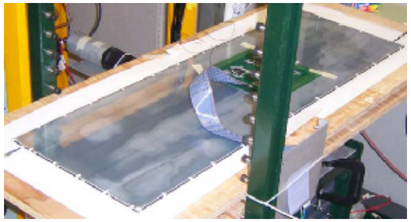
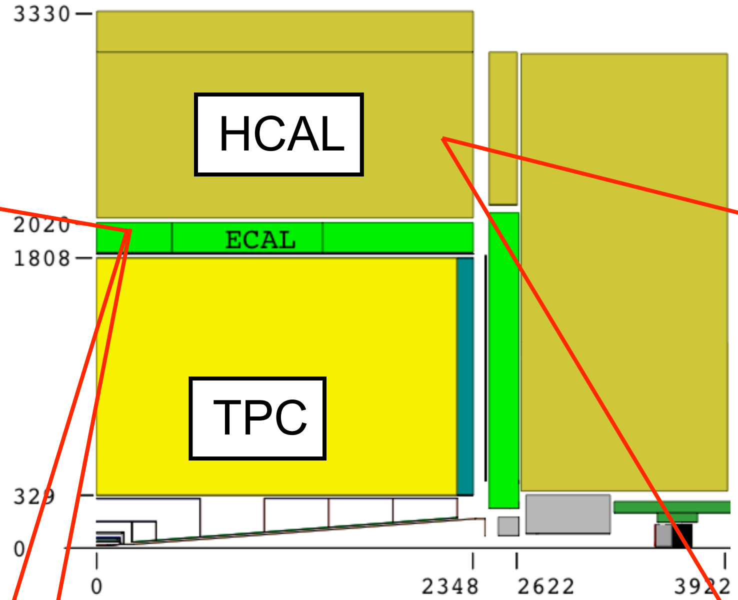


★ Steel RPC (Semi) Digital 1x1 cm2



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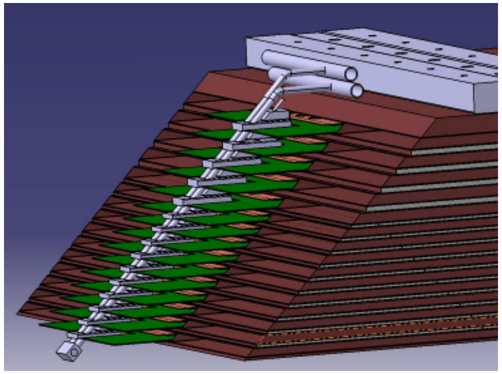
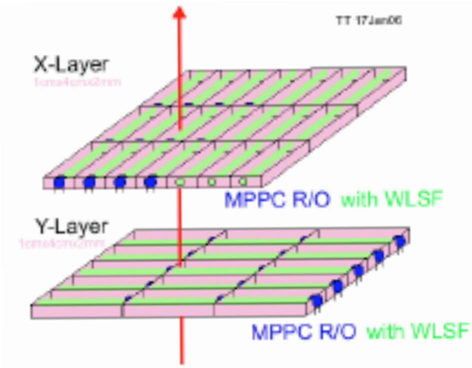


★ ScintW: 10x10 mm$^2$

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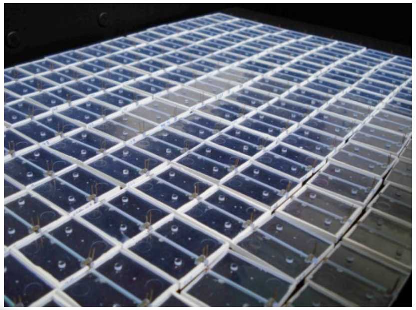

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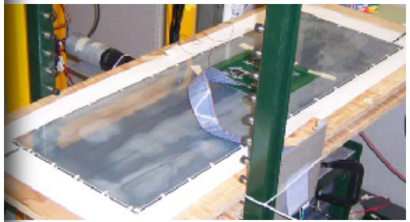


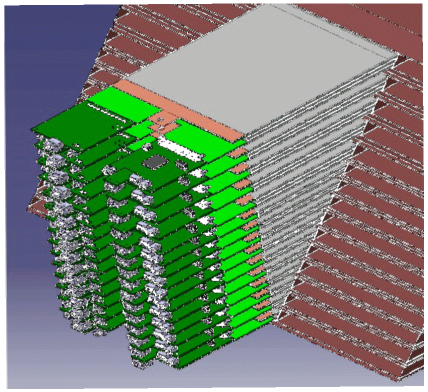
**Designed for Particle Flow:**

- high spatial granularity
- hermeticity
- longitudinal compactness
- reduced non-active areas: electronics integrated on detector wherever possible
  - ASICS mounted on active material
  - SiPMs / MPPC mounted on scintillators

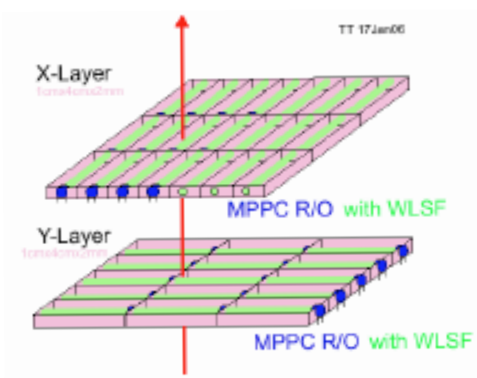
# Calorimeters for ILC (CALICE)

## ECAL

★ SiW: 5×5 $mm^2$



★ ScintW: 10x10 $mm^2$

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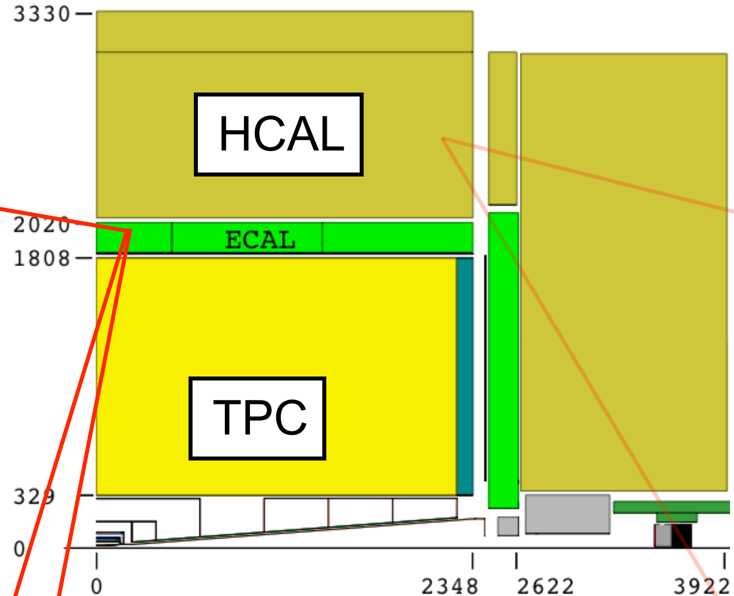


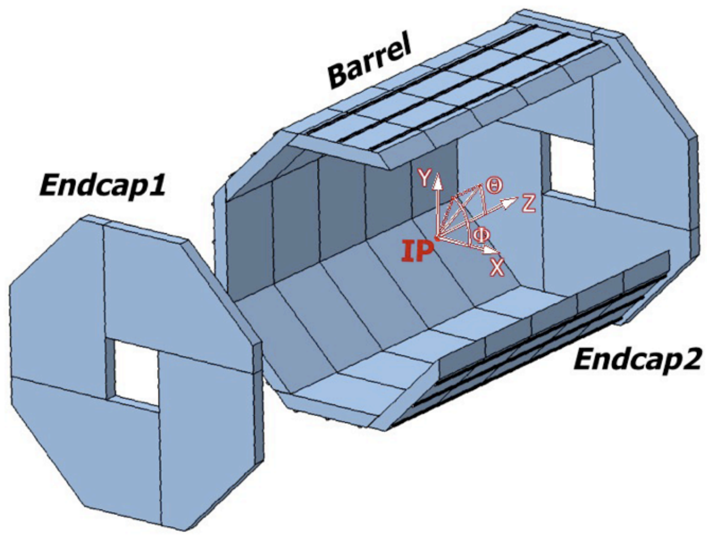


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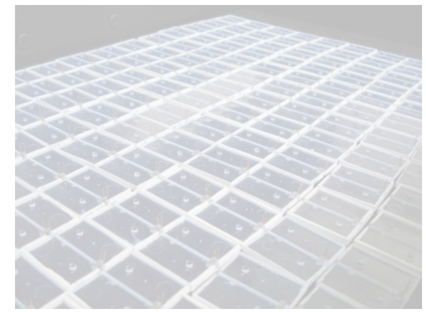

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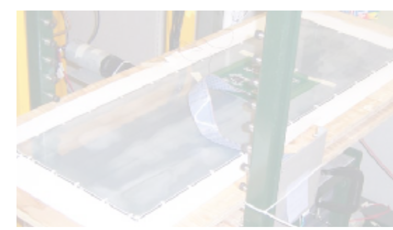
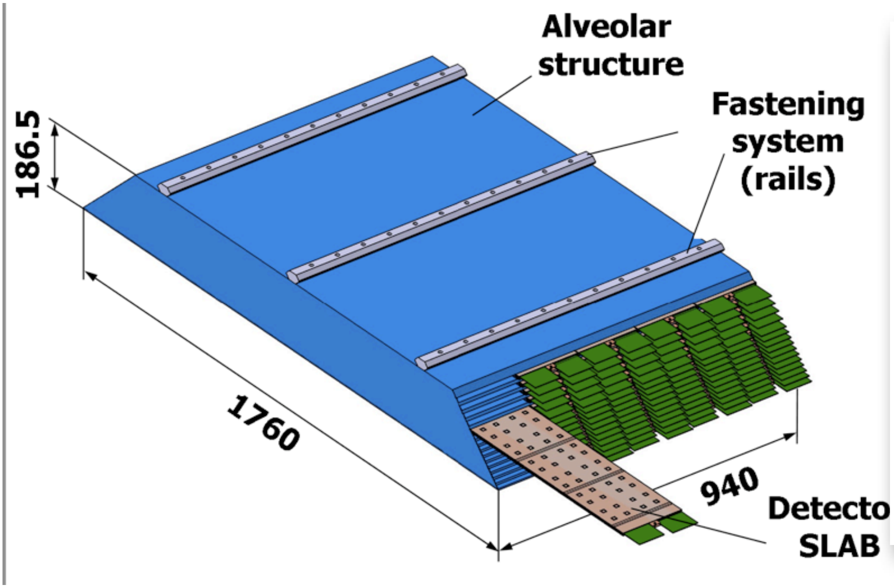





absorber: W
($R_M$=19 mm, $X_0$=3.5 mm, $\lambda_i$=99 mm)

~24 $X_0$ within 20 cm

longitudinal segmentation: 30-40 layers,
varying W thickness

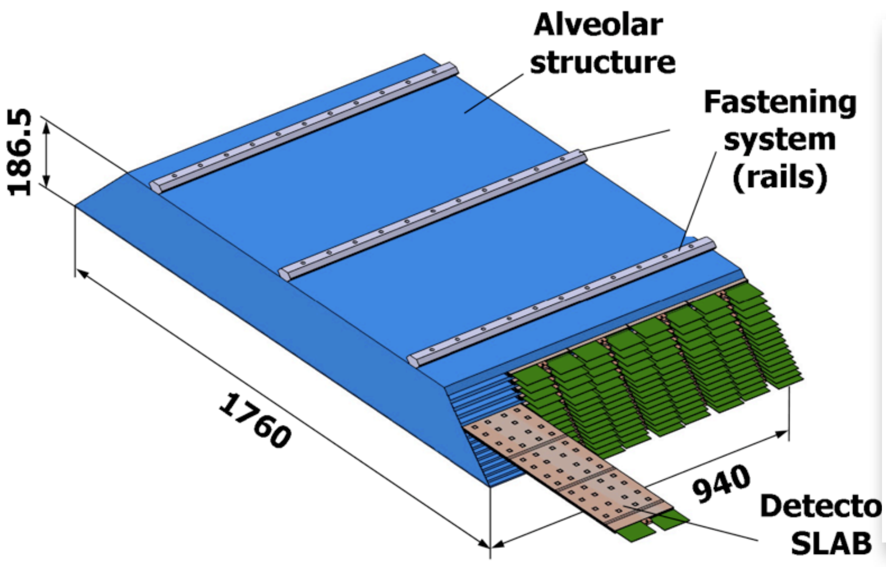
transverse segmentation: 5-10 $mm^2$

## SiW ECAL

- sensitive material: Si
- transverse segmentation: 5x5 $mm^2$
- 20 layers of 0.6$X_0$ (2.1mm) + 9 layers of 1.2$X_0$
- $10^8$ readout cells in total
- 2500 $m^2$ total sensor surface

## ScECAL

- sensitive material: Sci
- compact photosensors (MPPC)
- transverse segmentation: 10x10 $mm^2$
- 24 superlayers (3mm W plate, 2mm Sci strips, 2mm readout layer)
- 20.6 $X_0$, 172 mm in total
- $10^7$ readout cells

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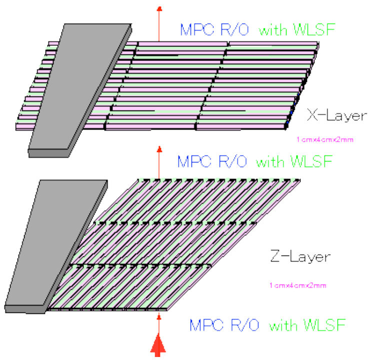
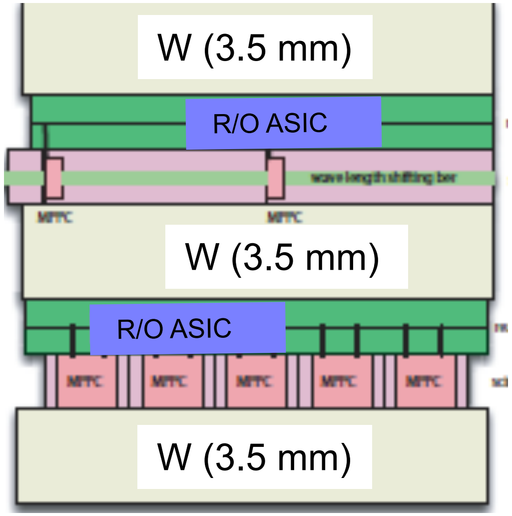
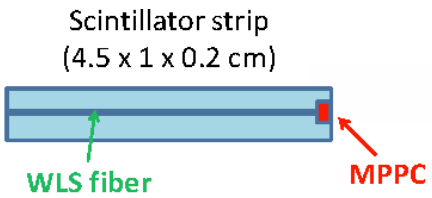
**Physics prototypes built and extensively tested with beams**
**Technological prototypes being built**

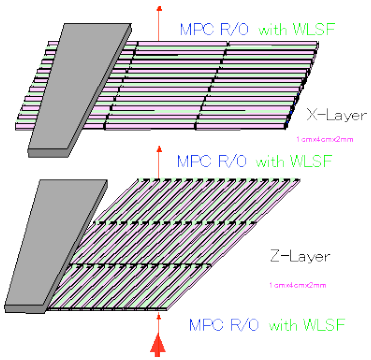



Extruded scintillator strip



# ScECAL Physics Prototype

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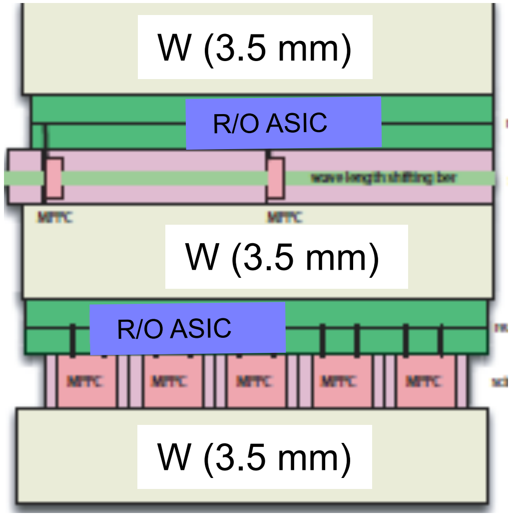


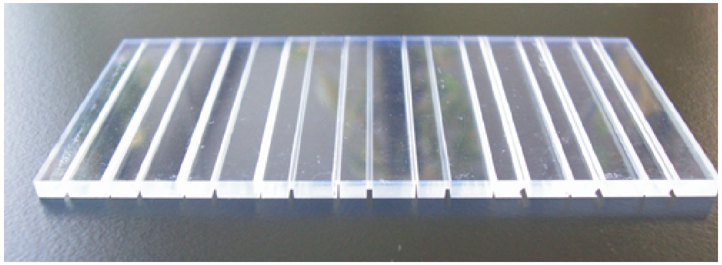

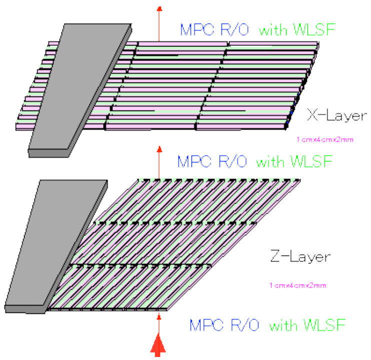


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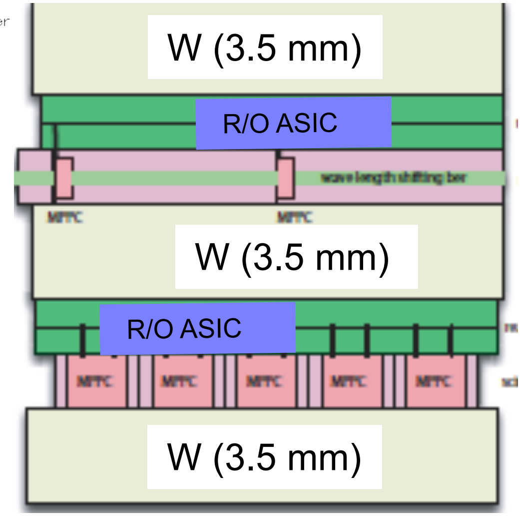


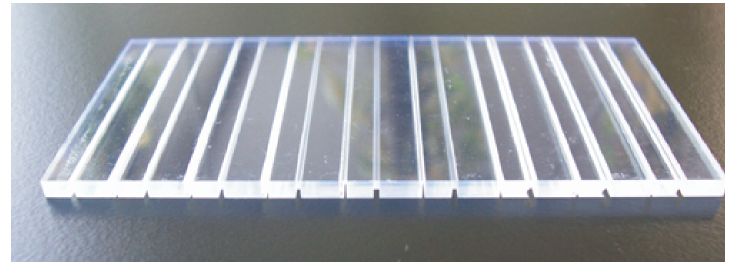

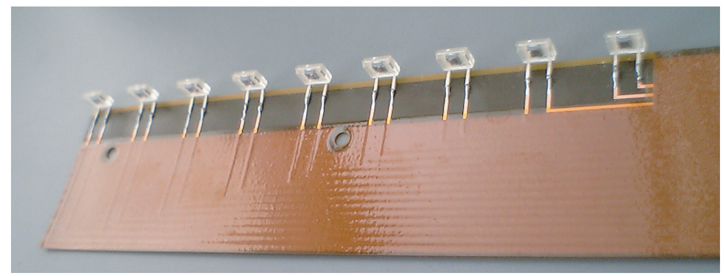

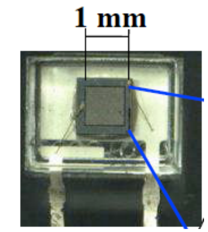

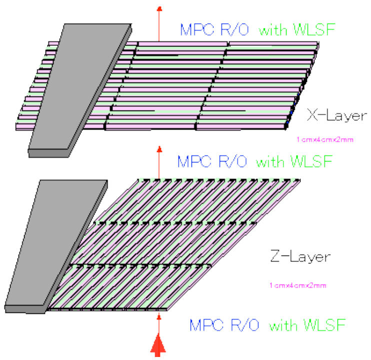


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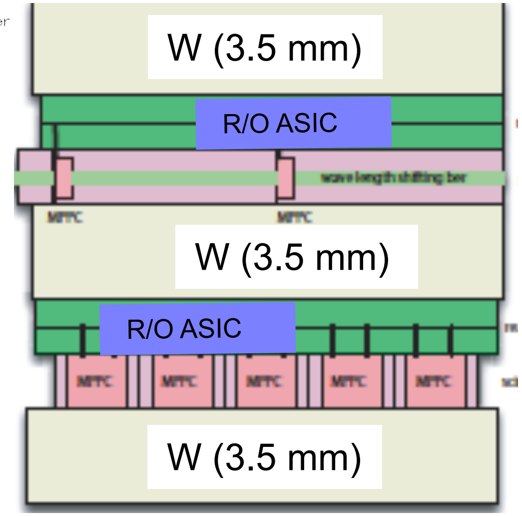
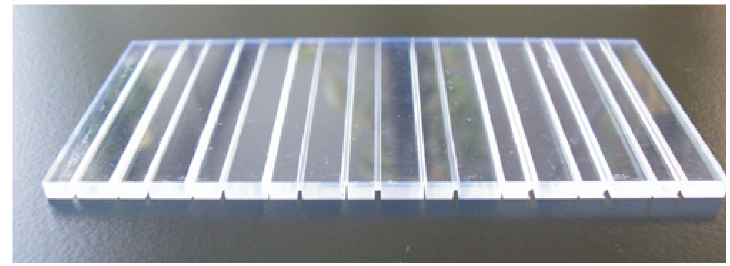
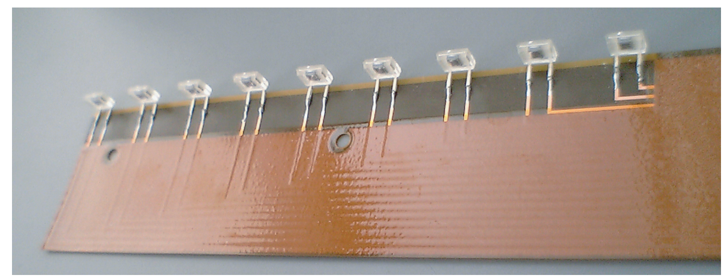
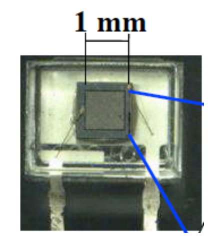
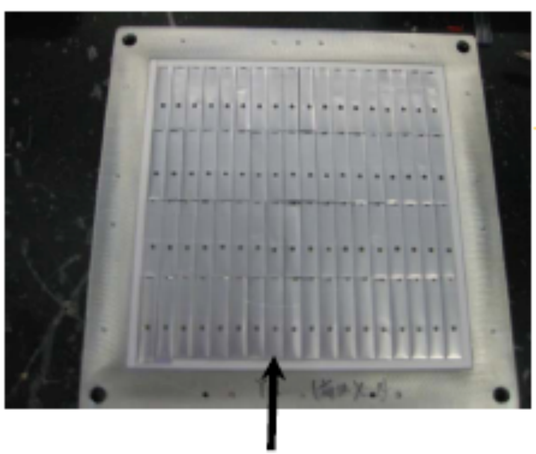


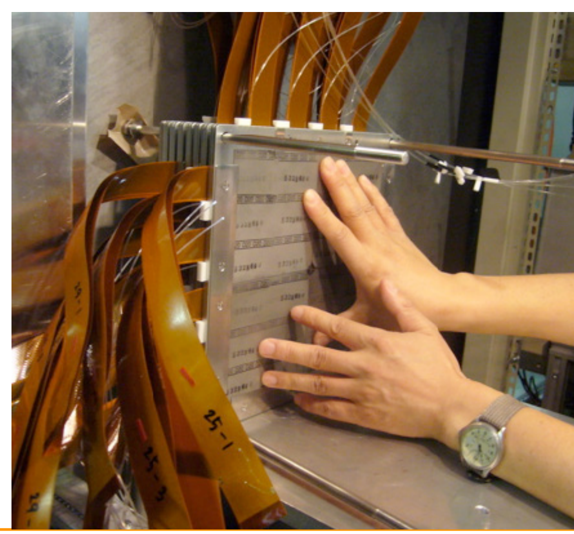



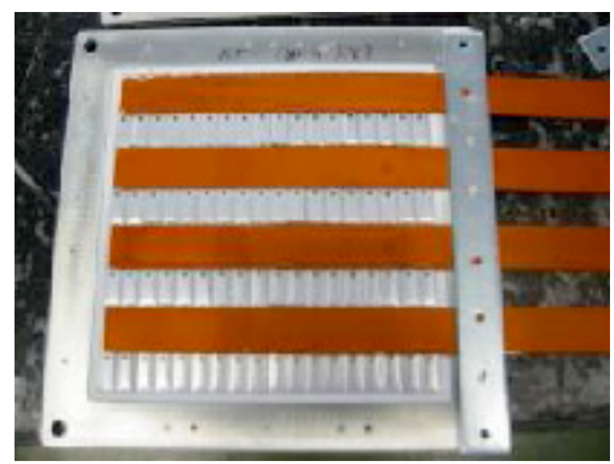


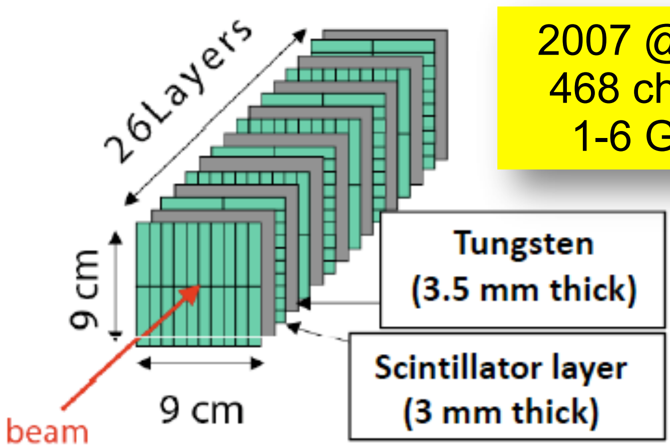


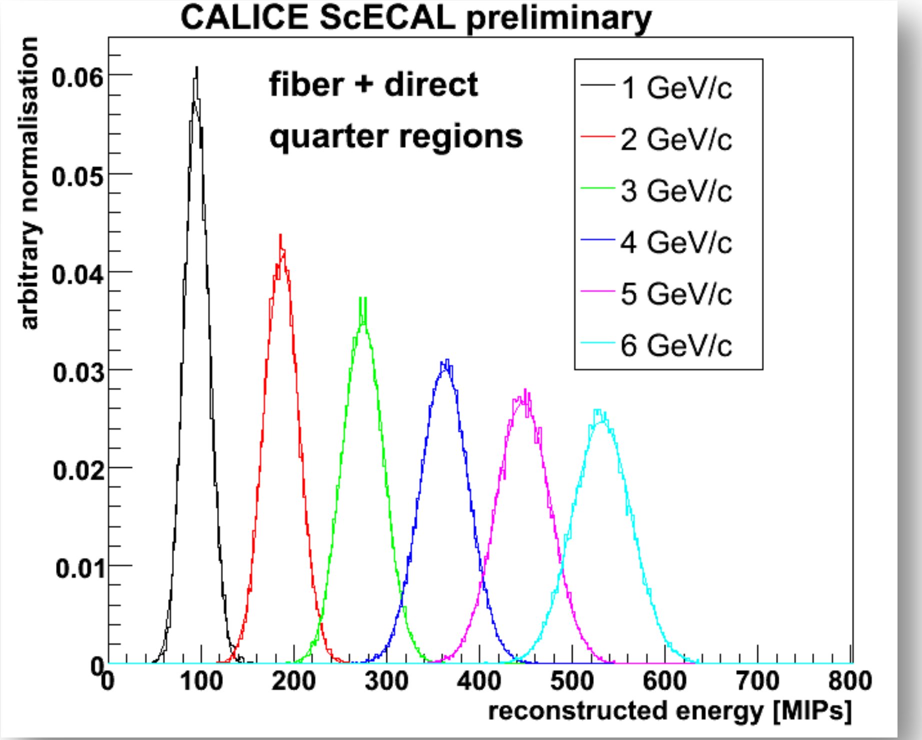
scintillator strip



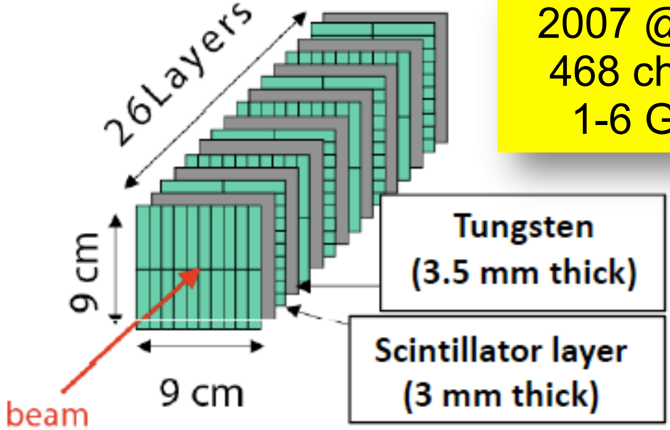





2007 @ DESY
468 channels
1-6 GeV $e^+$



# ScECAL Physics-Prototype: Testbeams

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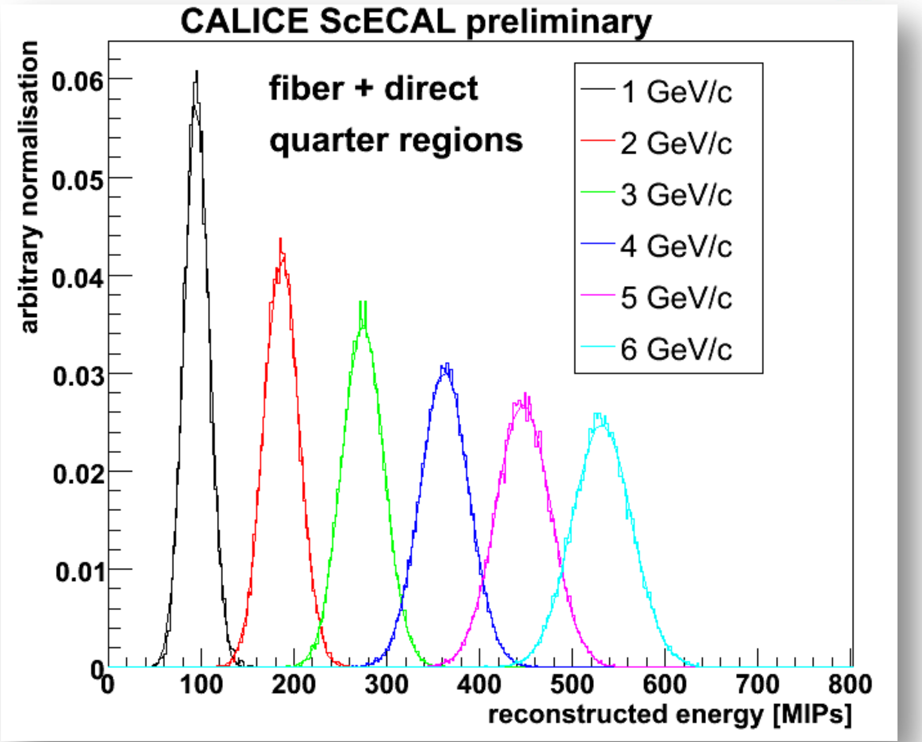
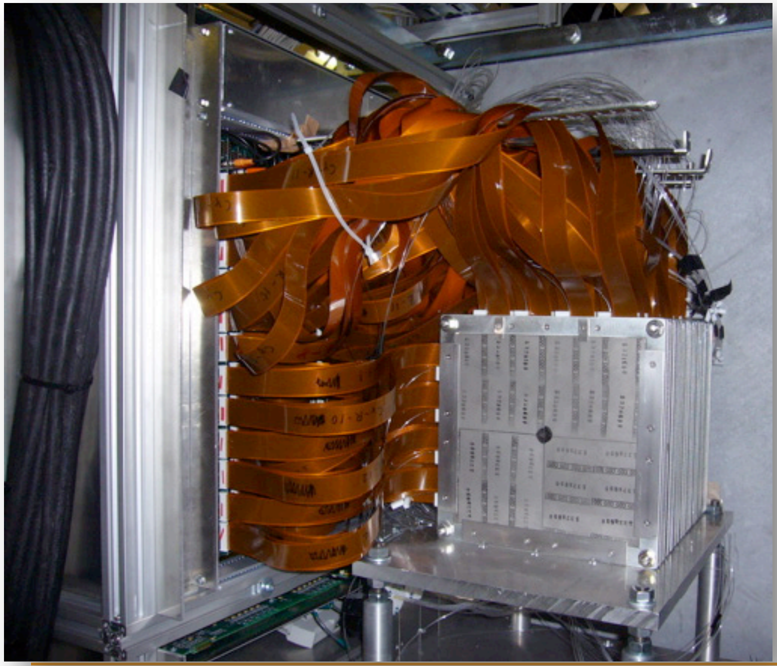
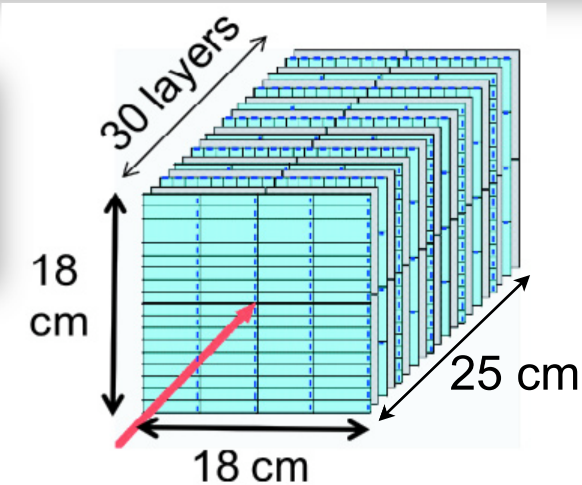


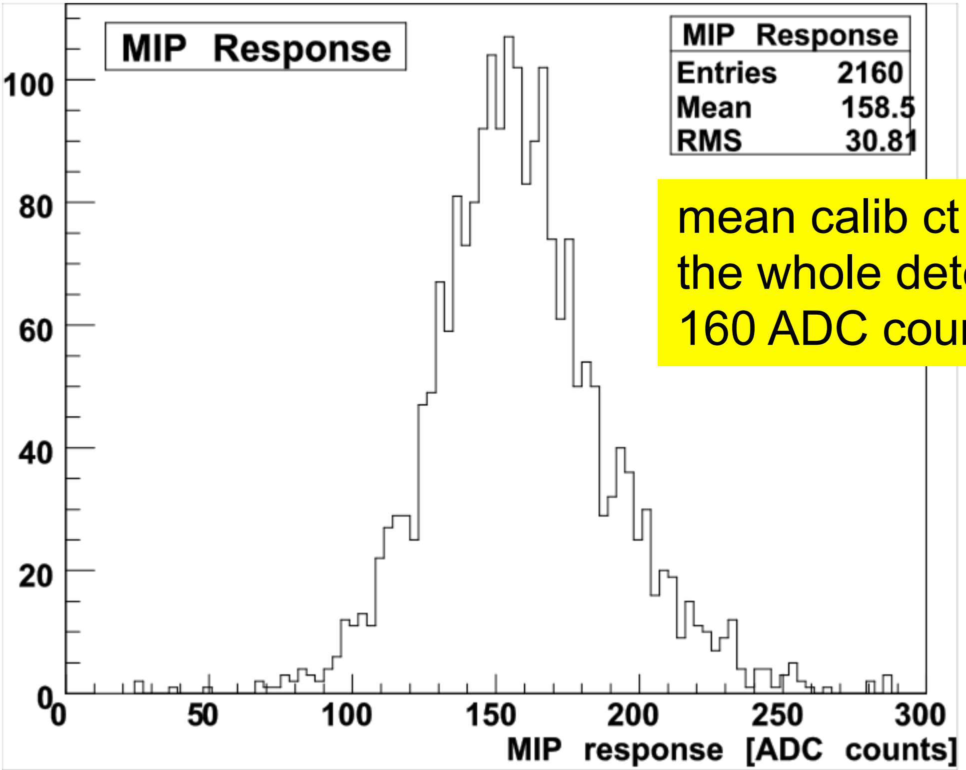



2008, 2009 @ FNAL
2160 channels
$e^+/e^-$ (1-32 GeV)
$\pi^+/\pi^-/\pi^0$ (1-60 GeV)



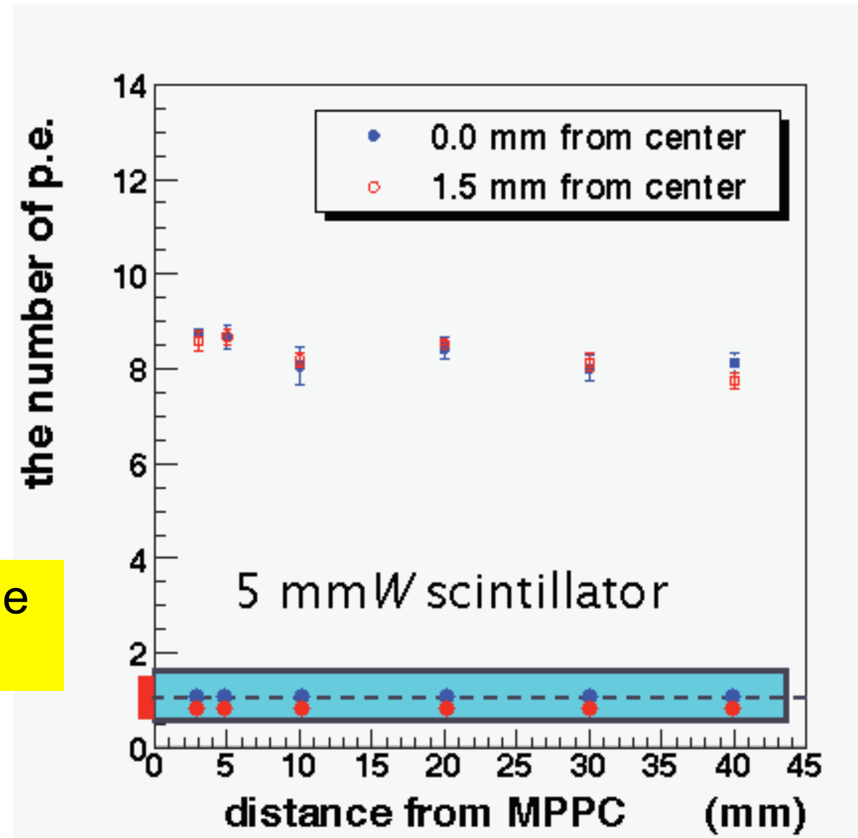
# ScECAL - MIP Calibration



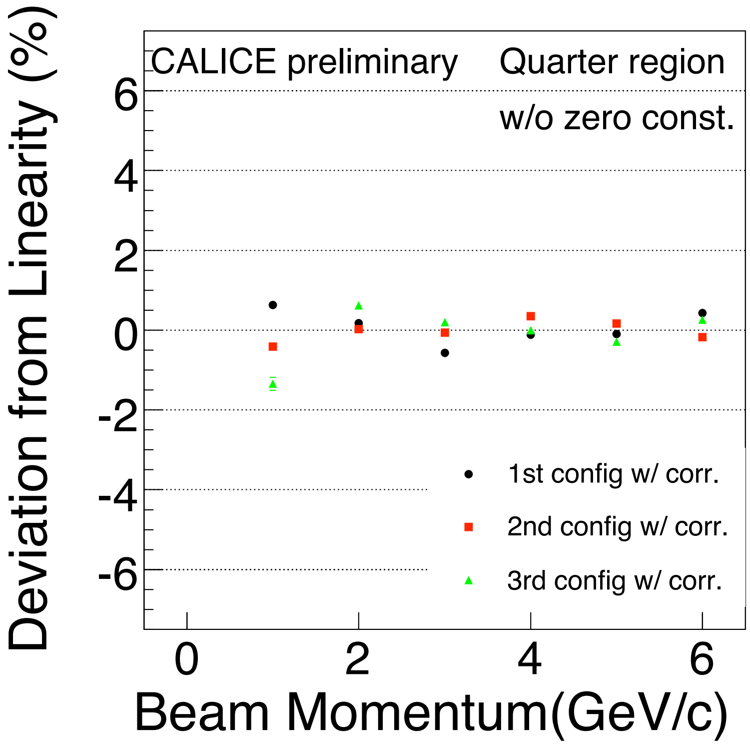


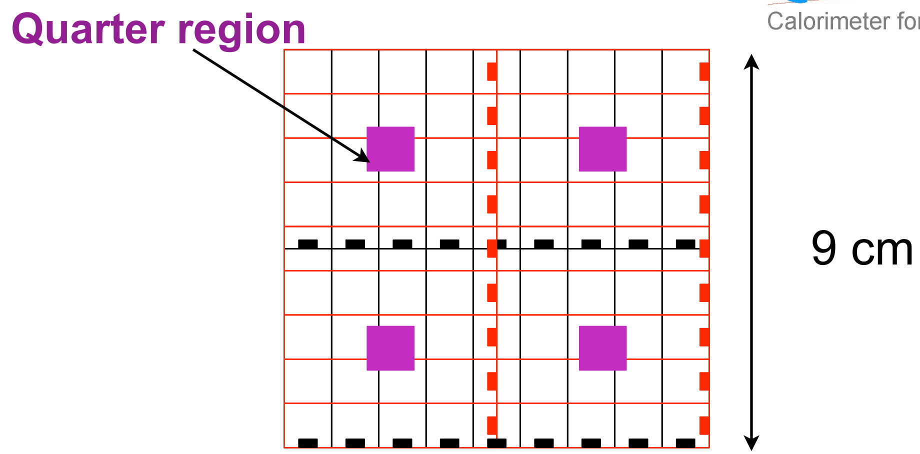

mean calib ct over the whole detector 160 ADC counts/MIP

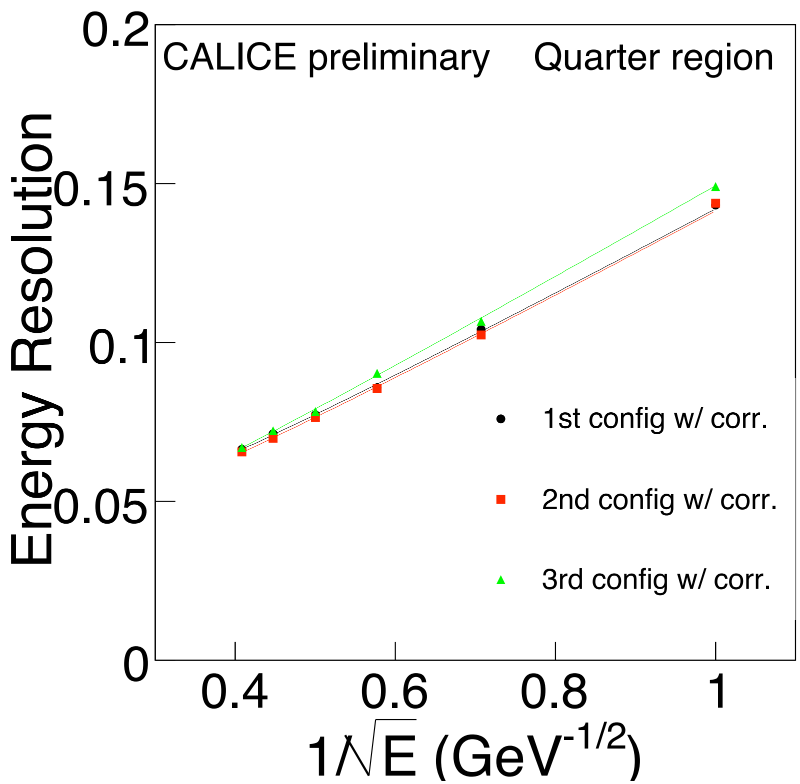
5 dead channels (0.23%)




uniformity along the strips



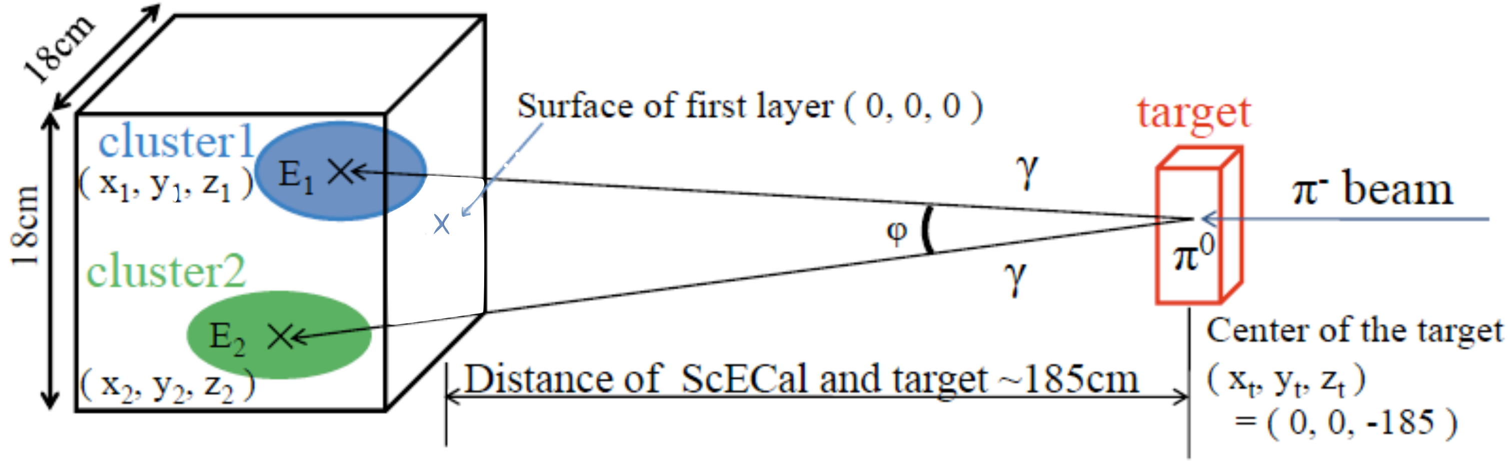

Non-linearities within 2%

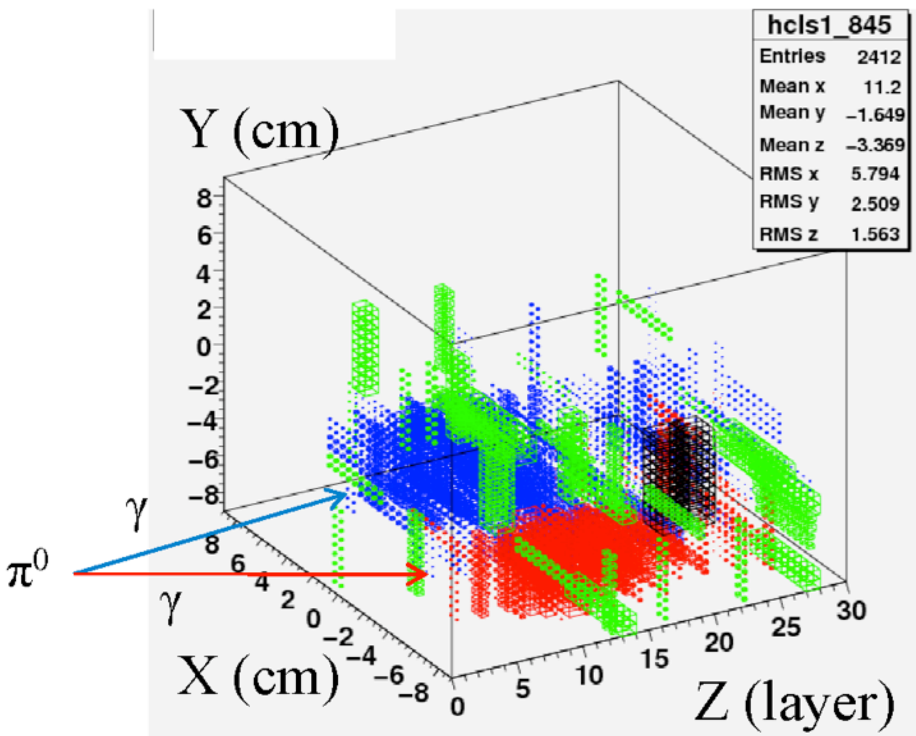
Stochastic term: ~14%

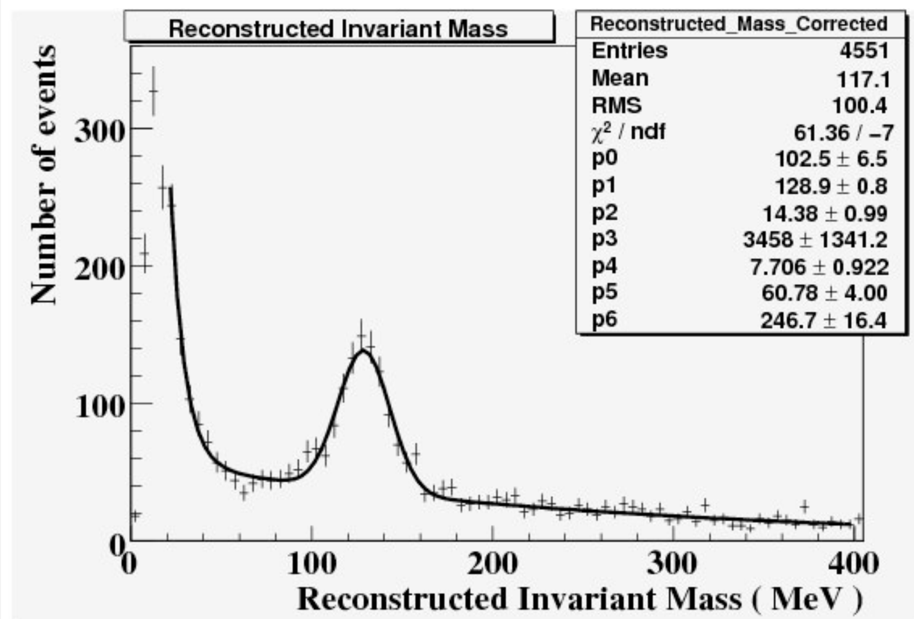
Constant term: ~3.3%

# ScECAL - $\pi^0$ reconstruction



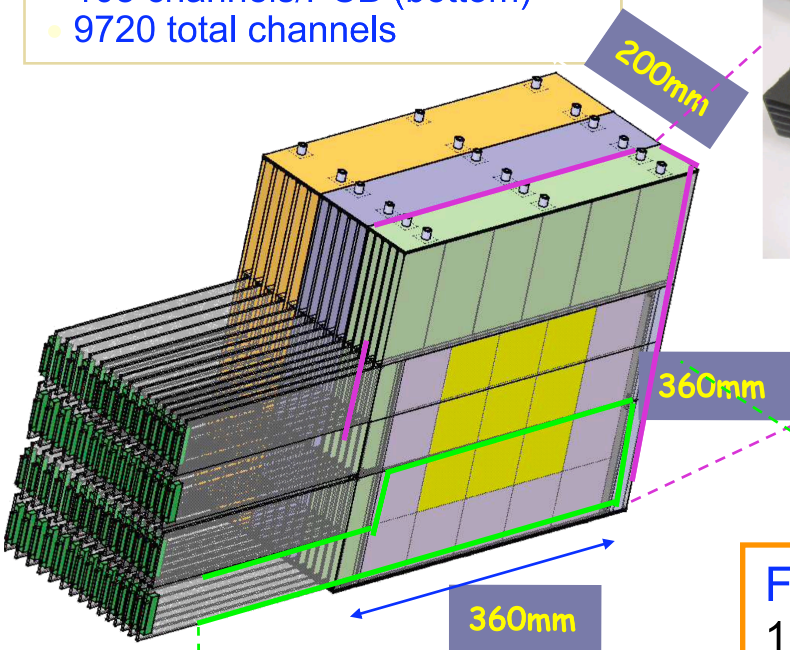


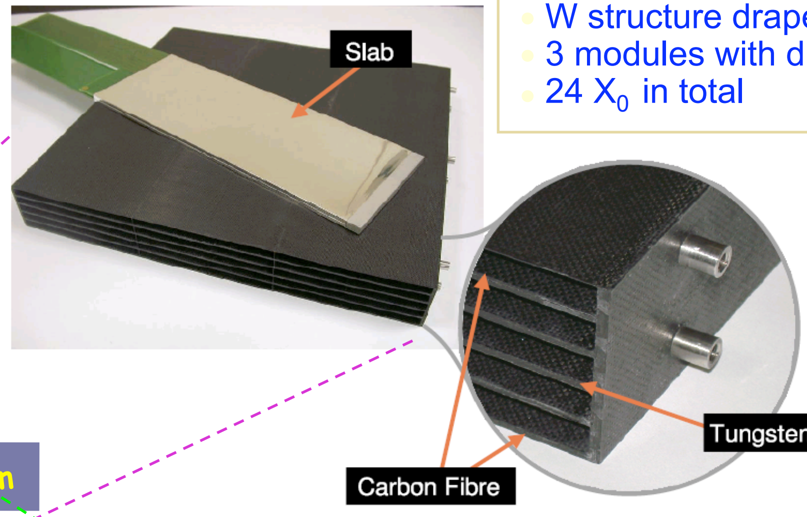



# SiWECAL Physics Prototype

- 60 PCBs (30 layers)
- 216 channels/PCB (centre)
- 108 channels/PCB (bottom)
- 9720 total channels



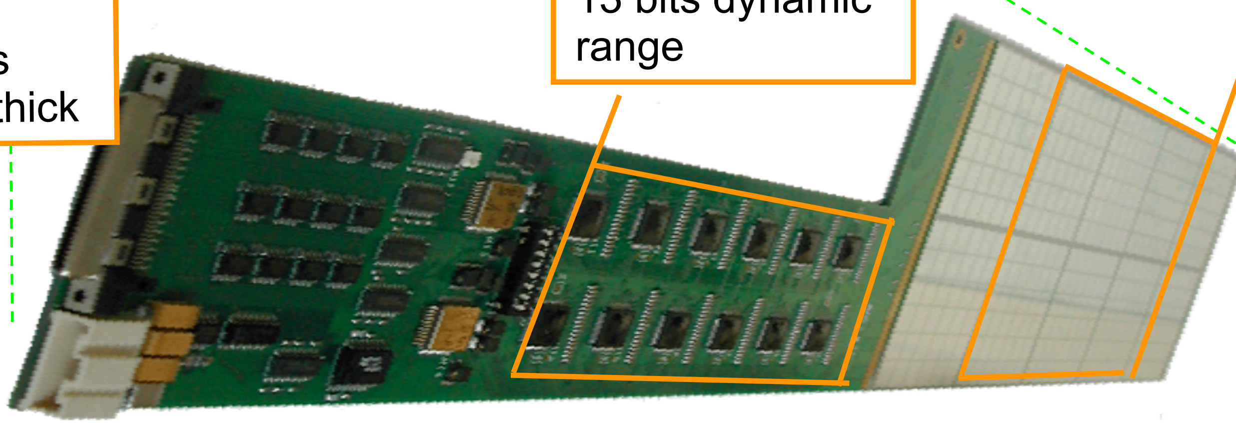




- W structure draped in carbon fibre
- 3 modules with different W thickness
- 24 $X_0$ in total

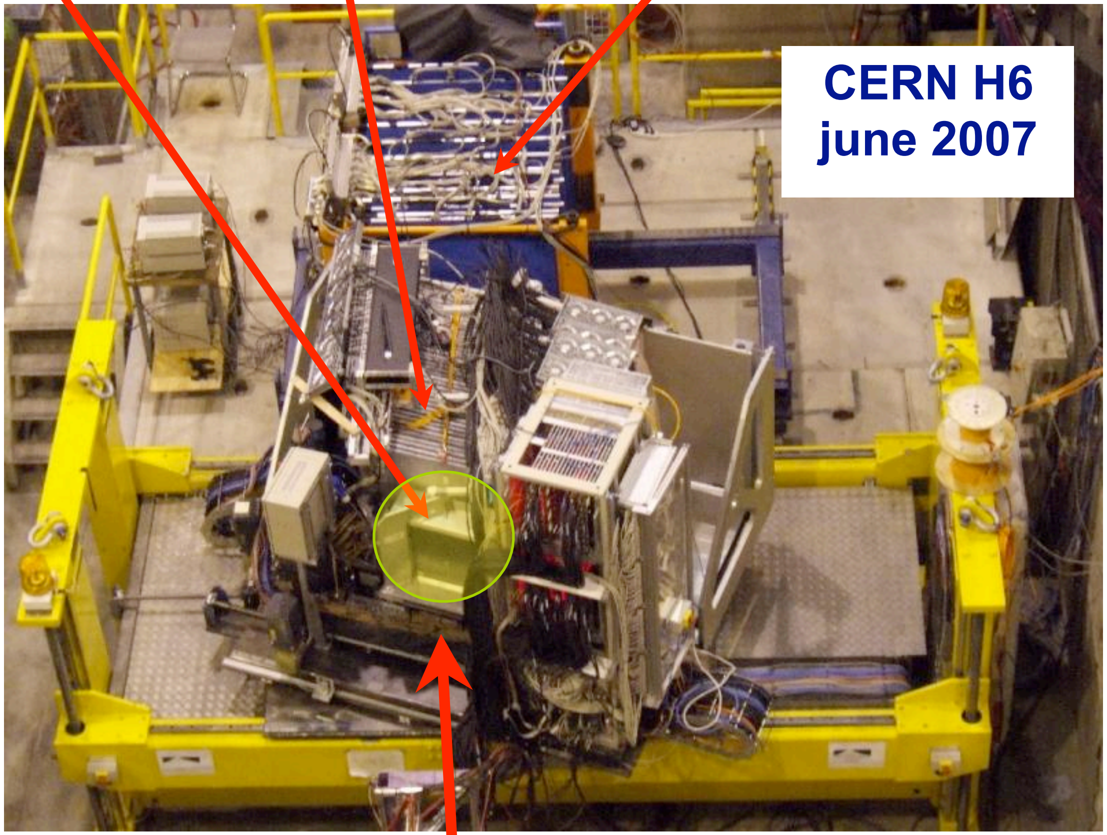
**PCB**
14 layers
2.1 mm thick

**Front End chip**
18 ch/chip
13 bits dynamic range

**6 active wafers**
36 Si PIN diodes
diode size: 1x1 cm
wafer size: 62x62 cm

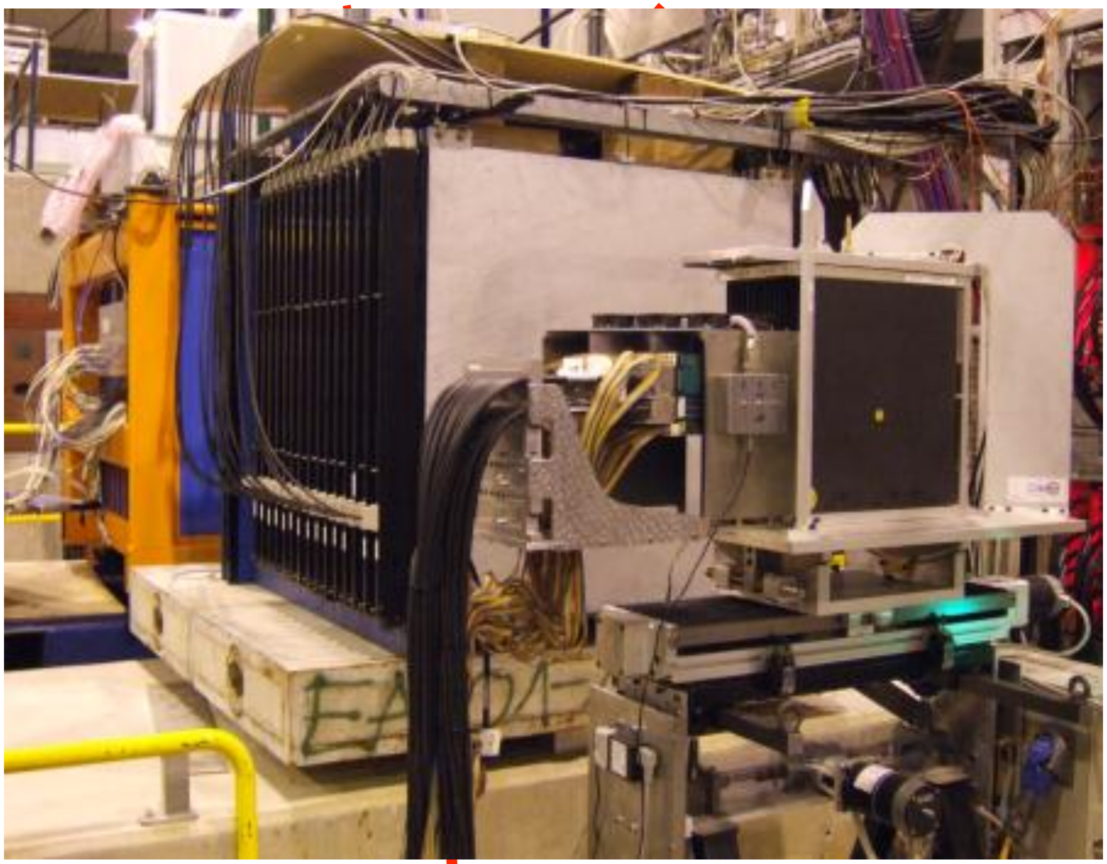


SiWECAL AHCAL TCMT



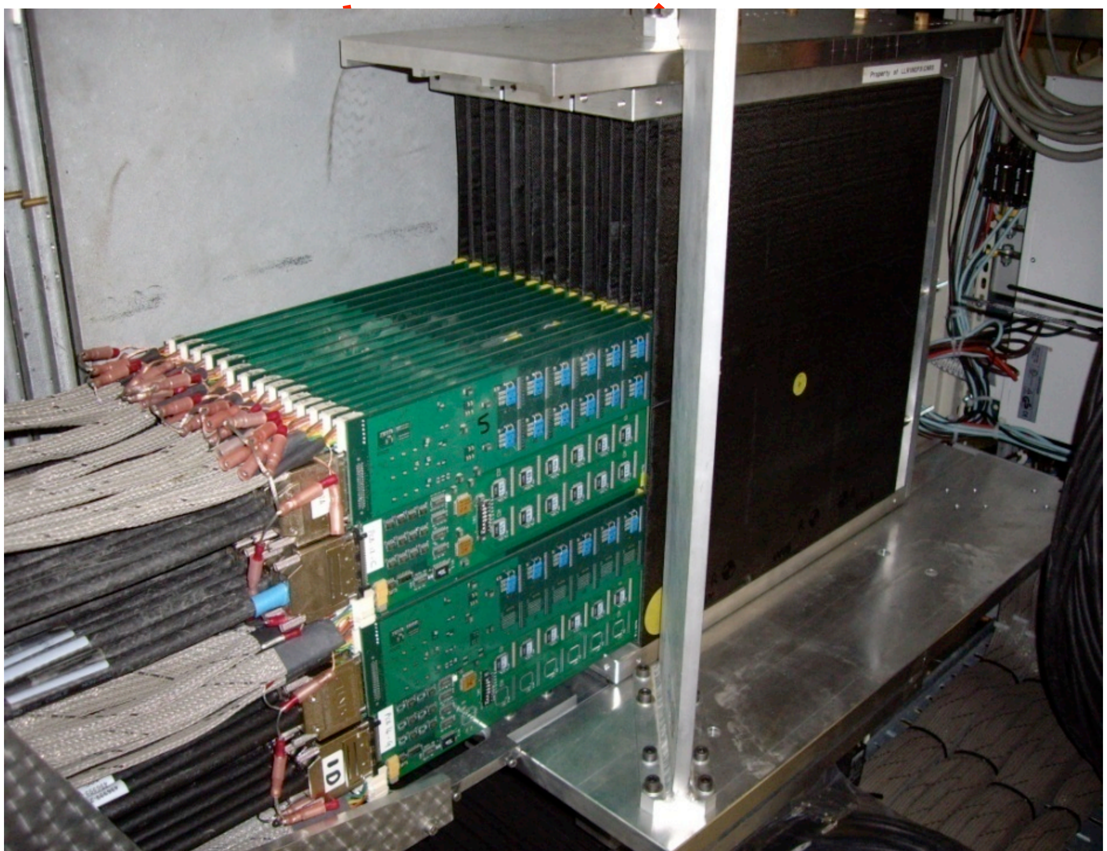

Beam

**SiWECAL** **AHCAL** **TCMT**




**Beam**

SiWECAL AHCAL TCMT



Beam

SiWECAL AHCAL TCMT

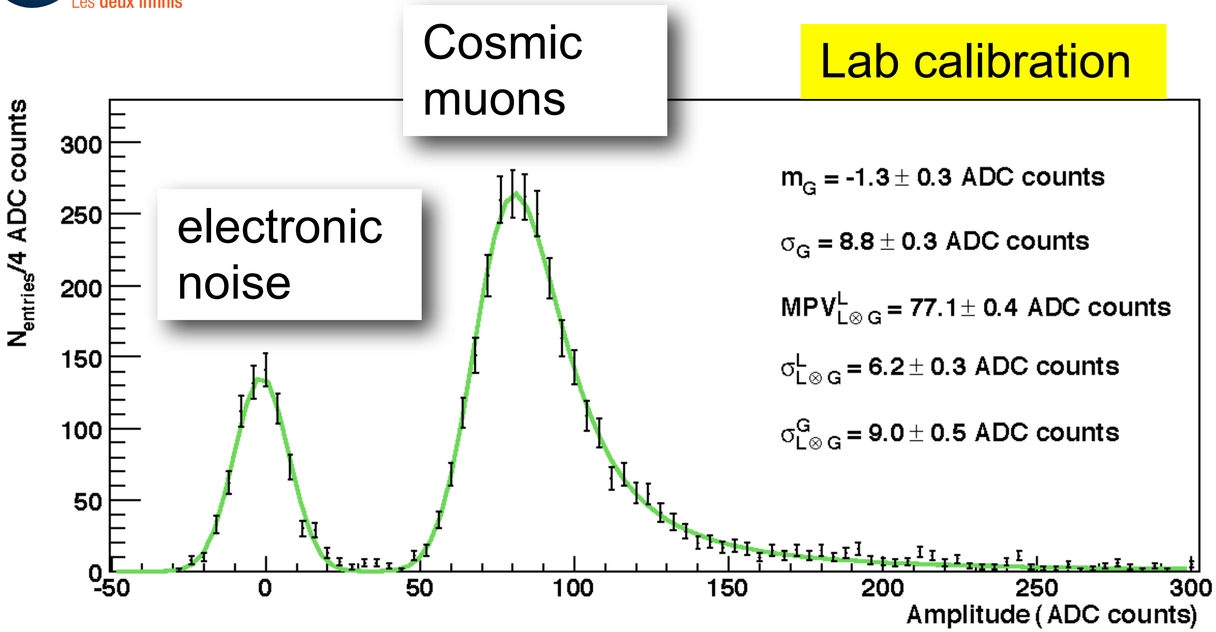
Beam

>65 M physics events

| location/date | nb channels | particles |
|---|---|---|
| DESY, 2006 | 5184 | $e^-$ (1 to 6 GeV) |
| CERN, 2006 | 6480 | $e^-$, $e^+$ (6 to 45 GeV)<br>$\pi^+$, $\pi^-$ (6 to 60 GeV) |
| CERN, 2007 | 9072 | $e^-$, $e^+$ (6 to 90 GeV)<br>$\pi^+$, $\pi^-$ (6 to180 GeV) |
| FNAL, 2008 | 9072 | $e^-$, $e^+$ (1 to 30 GeV)<br>$\pi^+$, $\pi^-$ (1 to 60 GeV) |

# SiWEcal Calibration

Lab calibration



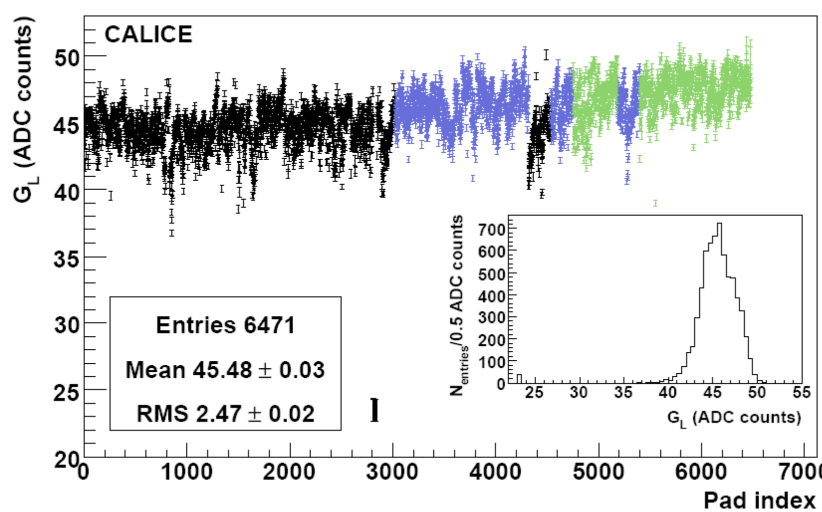

Beam calibration

Mean noise measured to be 12.9 ± 0.1 % MIP

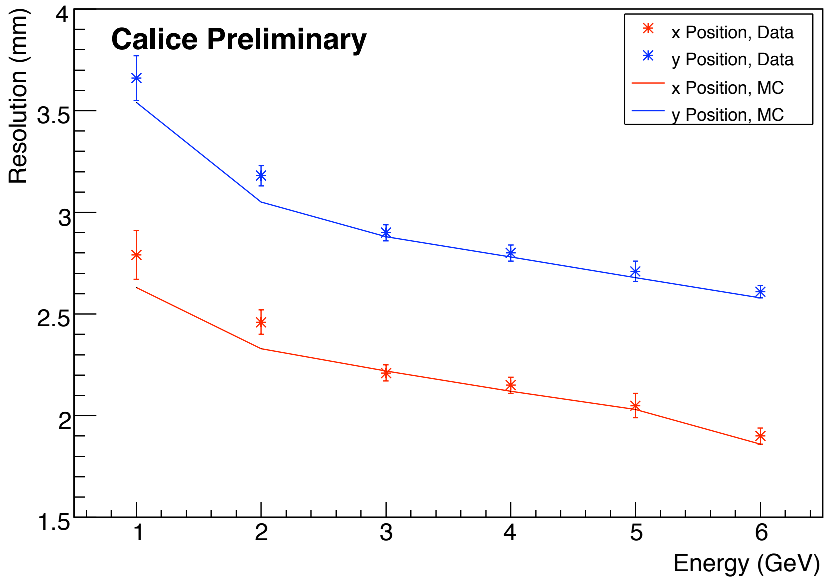
Noise cell-to-cell spread: 9% of the mean noise

Only 0.14% dead cells

- Calibrations in lab & in situ well correlated
- Very stable over the different TB periods
- Response level depends on
  - Production series (black-blue)
  - Manufacturer (black/blue – green)

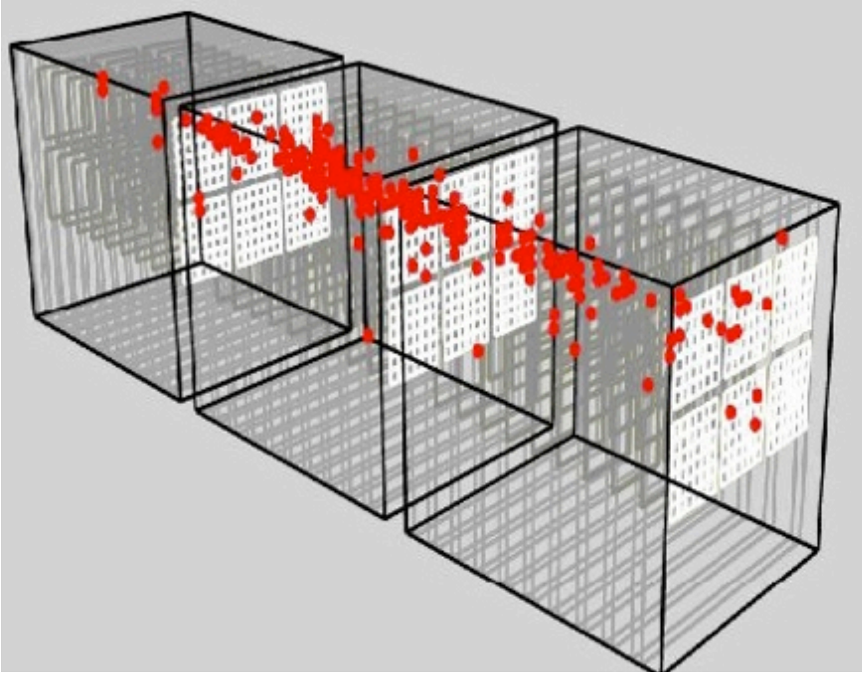


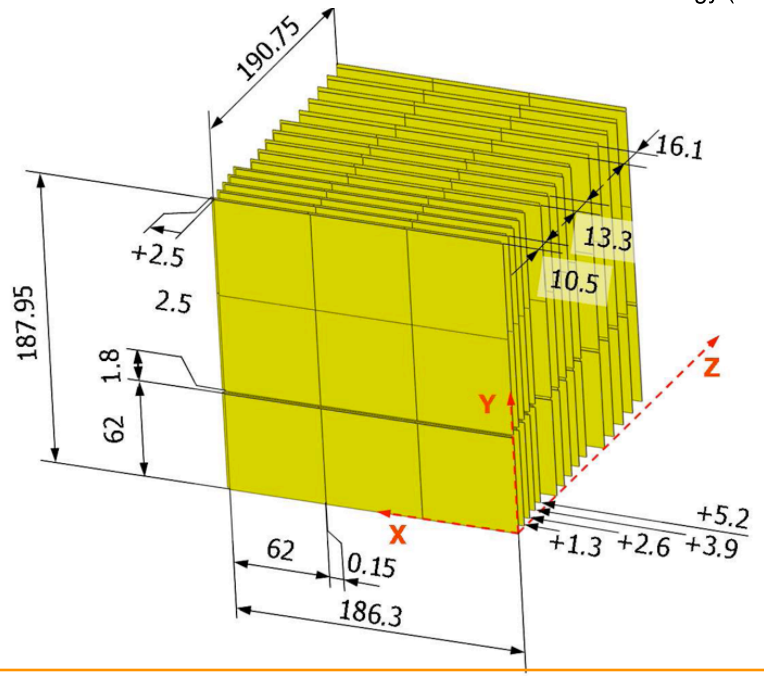
Position Resolution




Resolution better in $x$ than $y$ due to the $x$ staggering

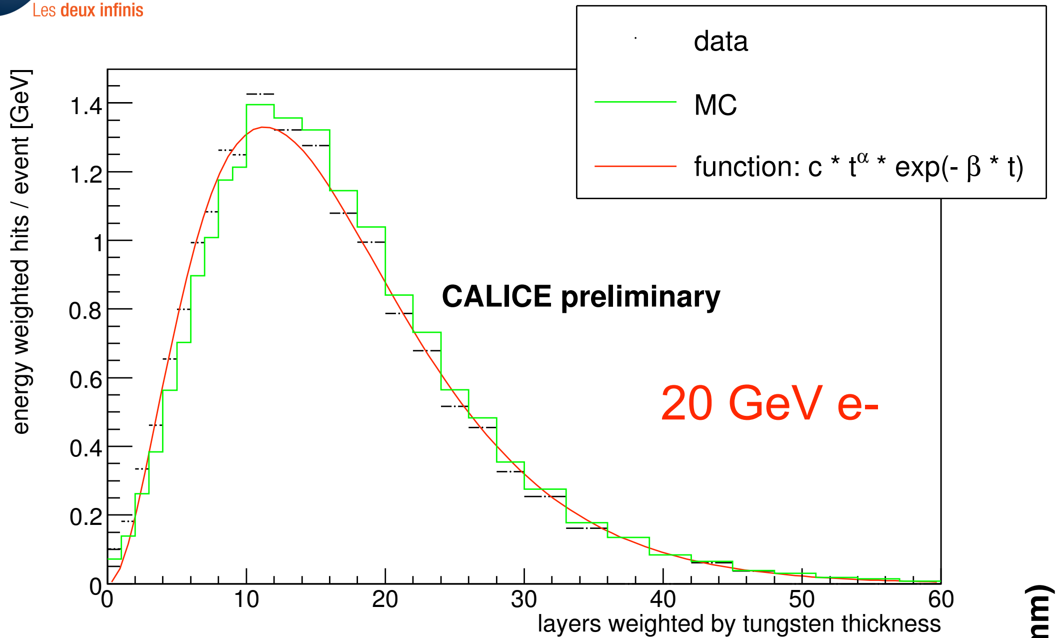
**10 GeV electron shower**

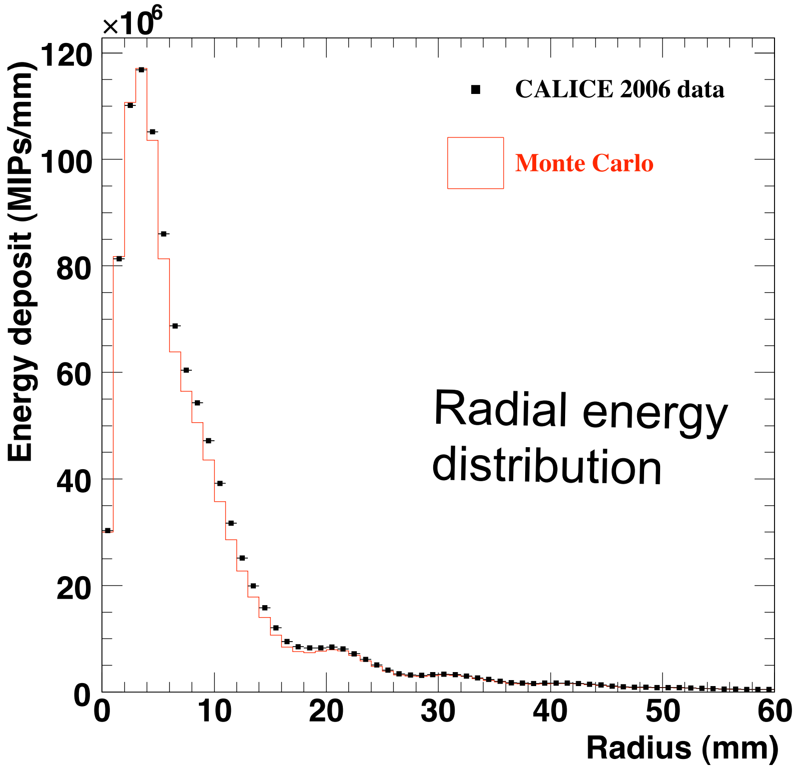


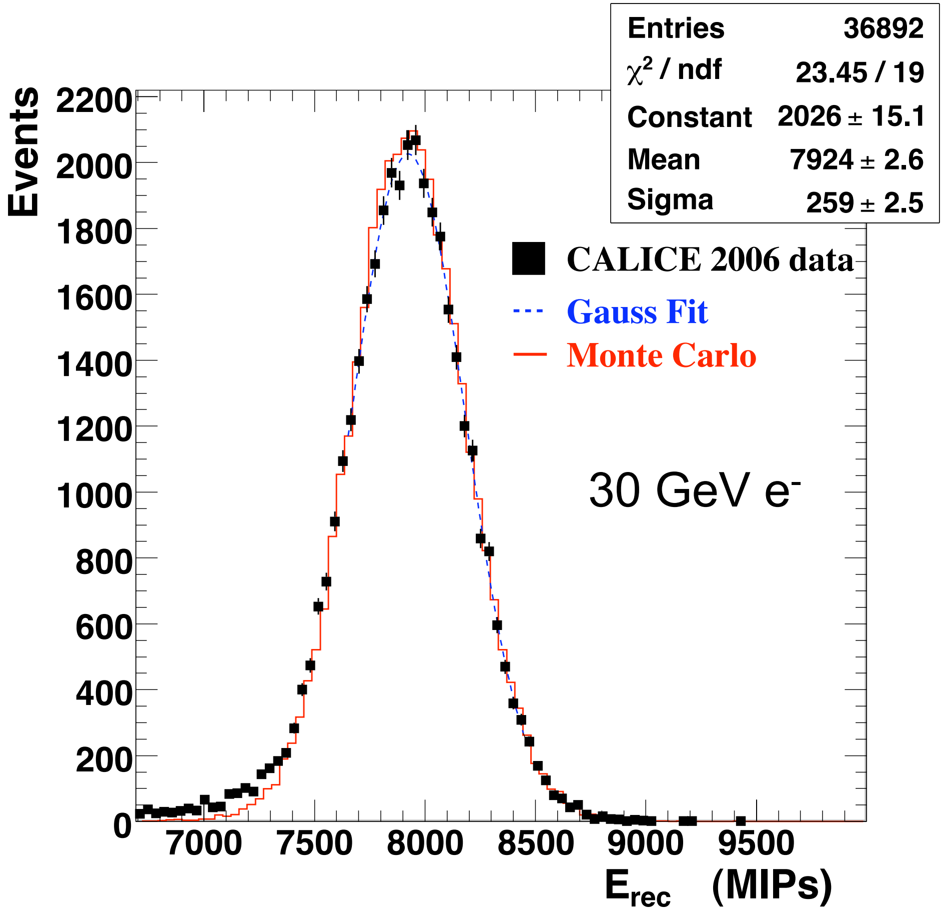


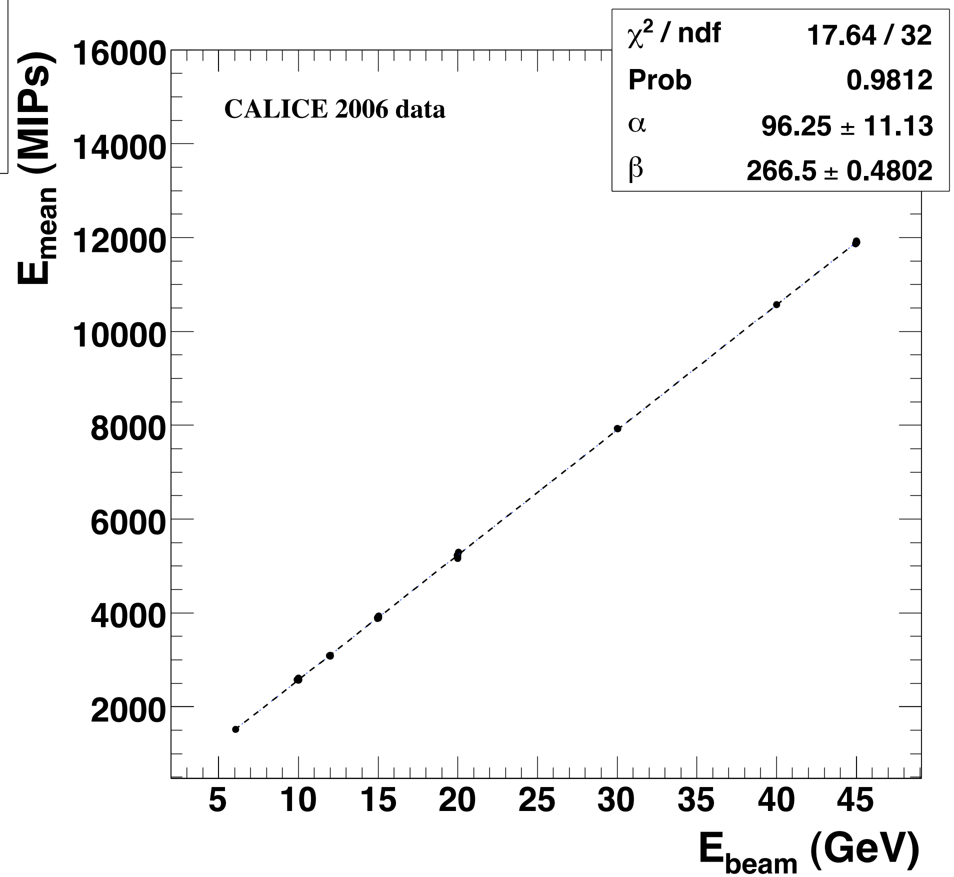
# SiWECAL- Profile of the Elm Showers





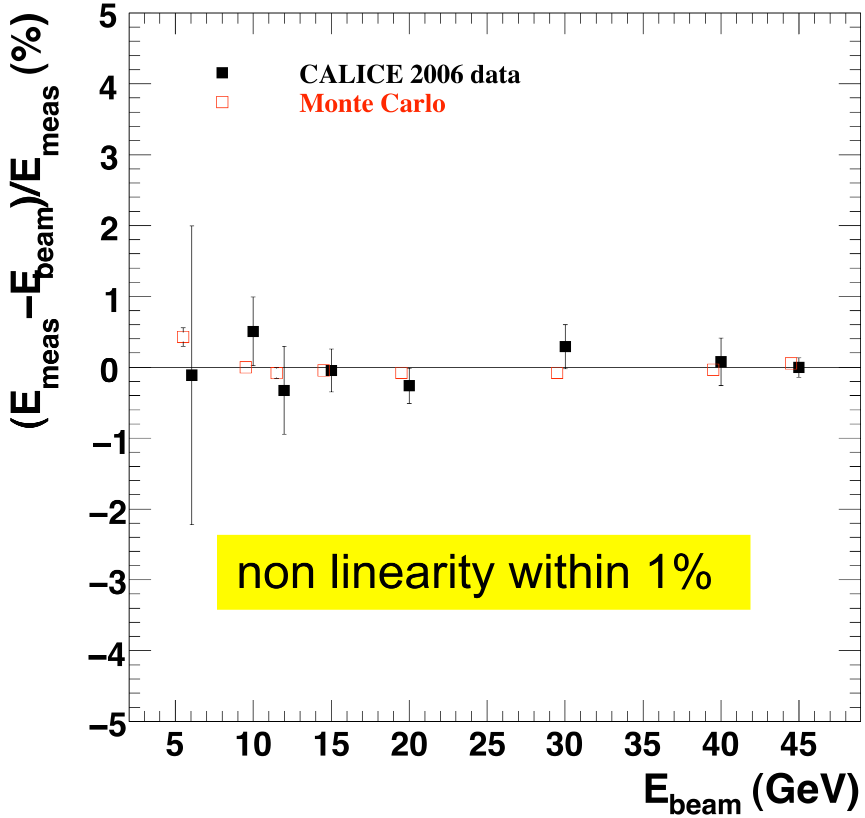



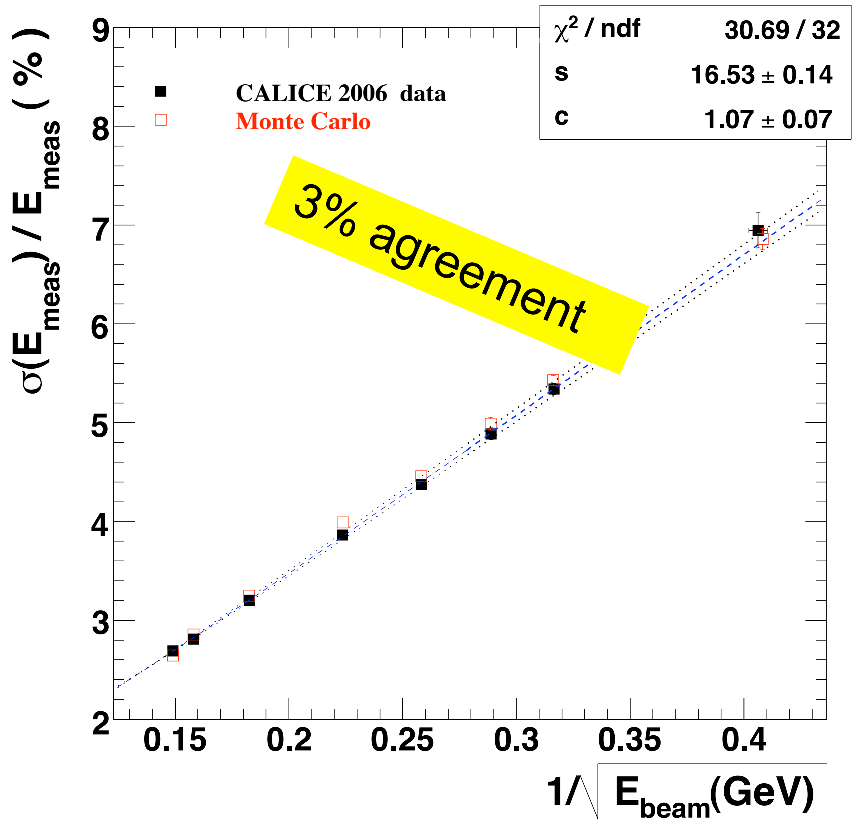

Entries 36892
$\chi^2$ / ndf 23.45 / 19
Constant 2026 ± 15.1
Mean 7924 ± 2.6
Sigma 259 ± 2.5
Events
CALICE 2006 data
Gauss Fit
Monte Carlo
30 GeV e-
$E_{rec}$ (MIPs)


$\chi^2$ / ndf 17.64 / 32
Prob 0.9812
α 96.25 ± 11.13
β 266.5 ± 0.4802
CALICE 2006 data
$E_{mean}$ (MIPs)
$E_{beam}$ (GeV)

# SiW ECAL Linearity & Resolution






$$\frac{\Delta E}{E}(\%) = \frac{16.53 \pm 0.14(stat) \pm 0.4(syst)}{\sqrt{E\ (GeV)}} \oplus (1.07 \pm 0.14(stat) \pm 0.1(syst))\ \%$$

$$\frac{\Delta E}{E}(\%) = \frac{17.06 \pm 0.13(stat)}{\sqrt{E\ (GeV)}} \oplus (0.82 \pm 0.09(stat))\ \% \quad \text{(simulation)}$$

# Conclusion

The tests with beams validated the CALICE physics prototypes:

- know how to build them
- easy to operate
- very stable in time
- robust calibrations, low noise
- uniform response to MIPs

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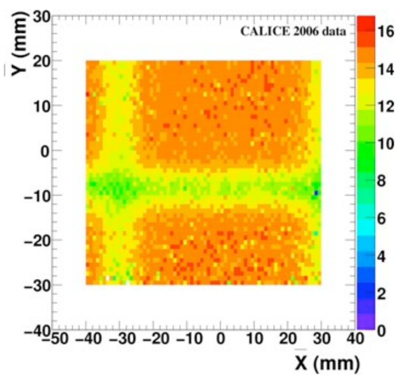


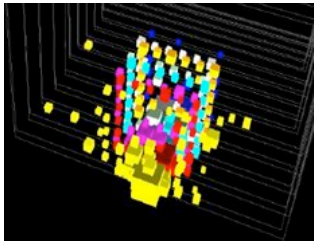

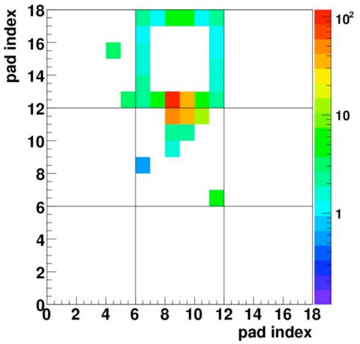

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- reasonable agreement with simulation

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Coming soon:

- VERY DETAILED shower development studies
- tracking performance

# The EUDET Module



Next (ongoing) step: build technological prototypes which
- integrate the mechanical, thermal and electric constraints for an ILD ECAL module
- include an embedded readout electronics
- allow for a realistic study of the construction processes.

| | Physics prototype | Technological Prototype |
|---|---|---|
| # Structures | 3: (10×1,4mm + 10×2,8mm + 10×4,2mm) | 1: (20×2,1mm + 9×4,2mm) |
| $X_0$ | 24 | ~23 |
| Dimensions | 380x380x200 mm$^3$ | 1560x545x186 mm$^3$ |
| Thickness of slab | 8.3mm (W=1.4mm) | 6 mm (W=2.1mm) |
| VFE | Outside | Inside (zero-suppressed r/o) |
| # channels | 9720 | 45360 |
| Cellsize | 10x10mm$^2$ | 5x5mm$^2$ |
| Weight | ~ 200 Kg | ~ 700 Kg |