Semiconductor sensors for the CALICE SiW EMC and Study of the Cross-talk between Guard Rings and Pixels in the CALICE SiW Prototype

-Silicon-Tungsten ECAL prototype
-Calibration & performance on test bench/beam
-Sensor behavior and design
-Crosstalk within sensors
-Summary and conclusion

Rémi CORNAT

LLR (CNRS/IN2P3)

XIII International Conference on Calorimetry in High Energy Physics, Pavia, Italy, 26-30 May 2008

On Behalf of the CALICE Collaboration

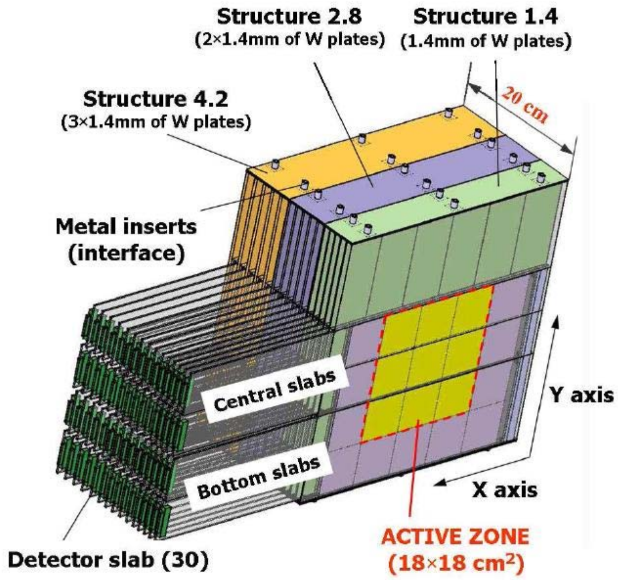
Running prototype of the CALICE ECAL

ILC design requires compactness

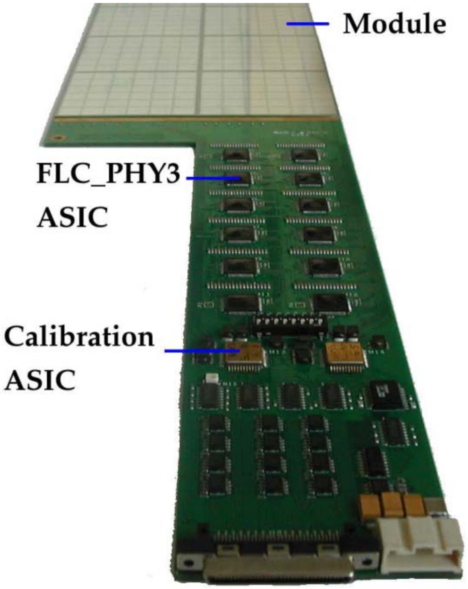
Particle Flow Algorithm helps to achieve the resolution target

Tungsten : small X0, small Rm

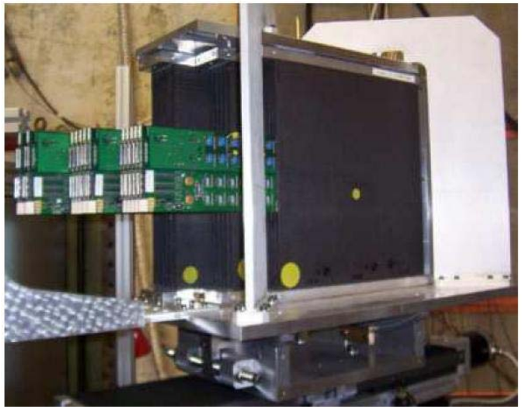
Silicon : high granularity



30 layers with variable sampling ratio (24 X0)
Interleaved with Si sensors
6x6 pads of 1x1 cm2 each



Physics performance :
- granularity
- Calibration
- Signal/Noise
- Time and temperature stability



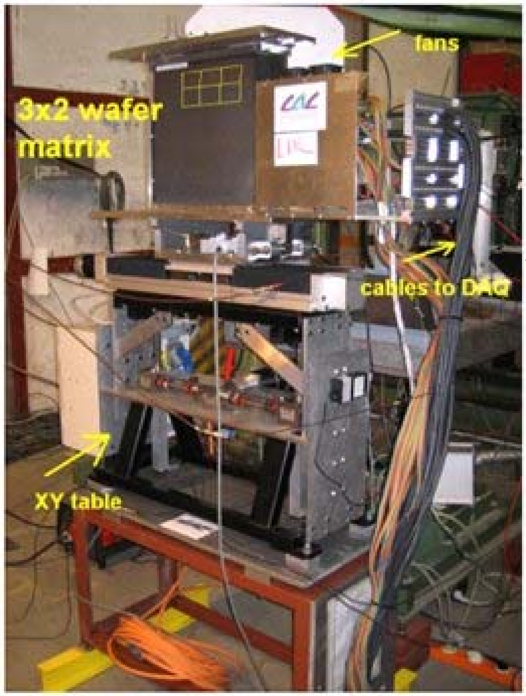
Evaluate technologies :
- carbon fiber alveolar structure
- Silicon-PCB-tungsten sandwich
- Integrated circuits
- Si Sensors

Tests of the prototype

2 complementary approaches

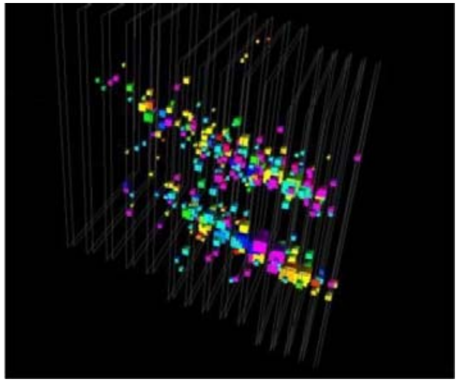
Test bench for individual components and
(Cosmic rays)

Test beam for the whole detector
DESY and CERN 2006, 2007



- DESY (1 to 6 GeV) and CERN (6 to 50 GeV) in 2006
- Various angle form beam studied
- 100M event collected (e, pi, mu)

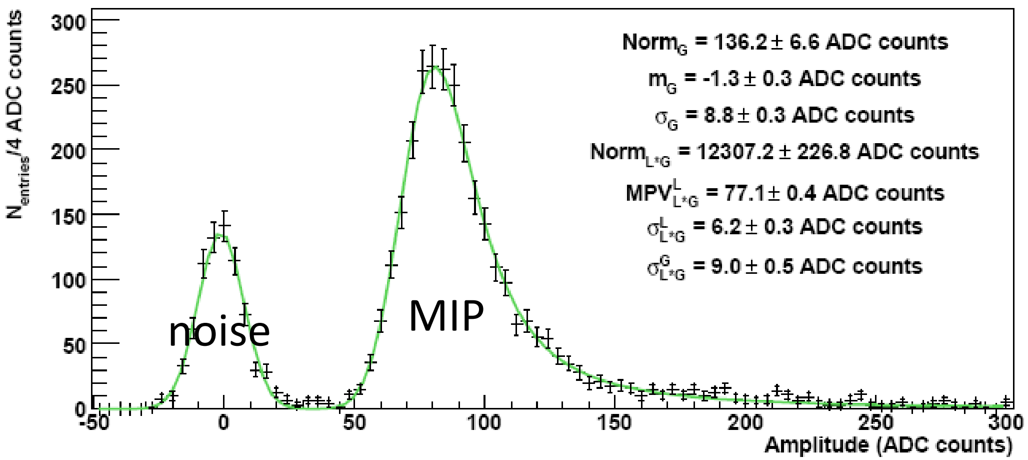
1 goal : have a realistic detector with characteristics close to what obtained in simulation and near expectations
S/N = 10 bits



1 achievement : a lot of issues overcame to get this

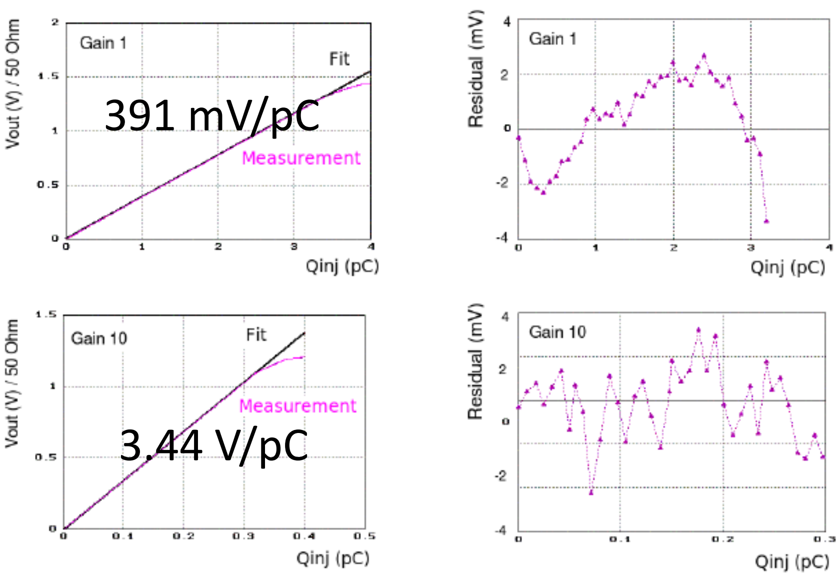
Module validation on test bench

Cosmic ray calibration tests bench



Fits give calibration constants on a channel per channel basis

Stand alone electronics



S/N = 9 (0.1 MIP)

Dynamic range of 15 bits (multiple gains)

Non linearity of 0.36% (high gain)

Electronics crosstalk less than 0.1%

Power is only 4 mW/channel (target is 100 uW)

Sensors intimacy

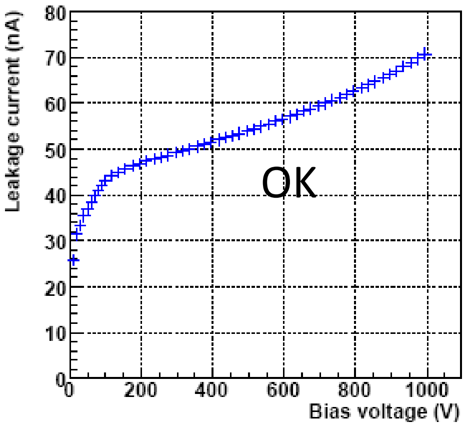
Find a low cost but effective sensor

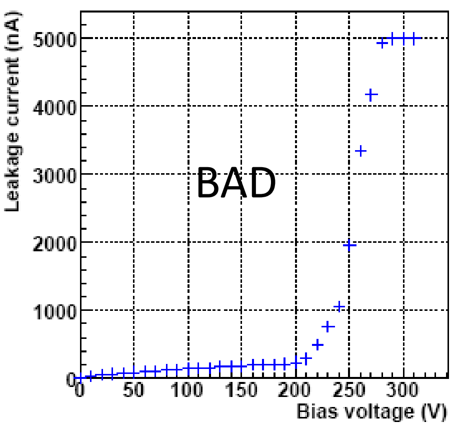
Why ? 3000 m2 to be produced !

How ? Smallest number of fabrication steps
•PIN diodes with floating guardrings
•Easy to integrate : gluing

•Low leakage current (<10 nA/cm2)
•Full depletion for maximum energy deposition
•Stable in time and for gluing

- Validate sensor processing prior to gluing
- 3 production batches (2005-2007)
  - Russian (Moscow State University)
  - Czech (Institute of Physics)
  - Korean
- 6x6 pads, 525 um thick, 200V bias
- MIP = 42000 electrons





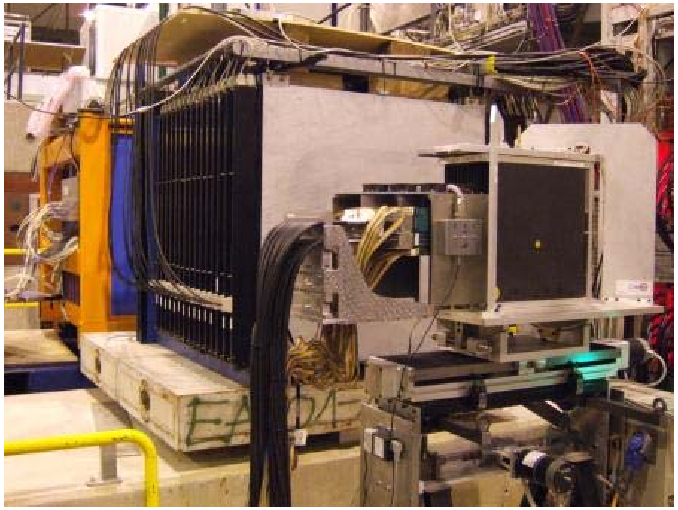
I(Vbias) : leakage
C(Vbias) : depletion

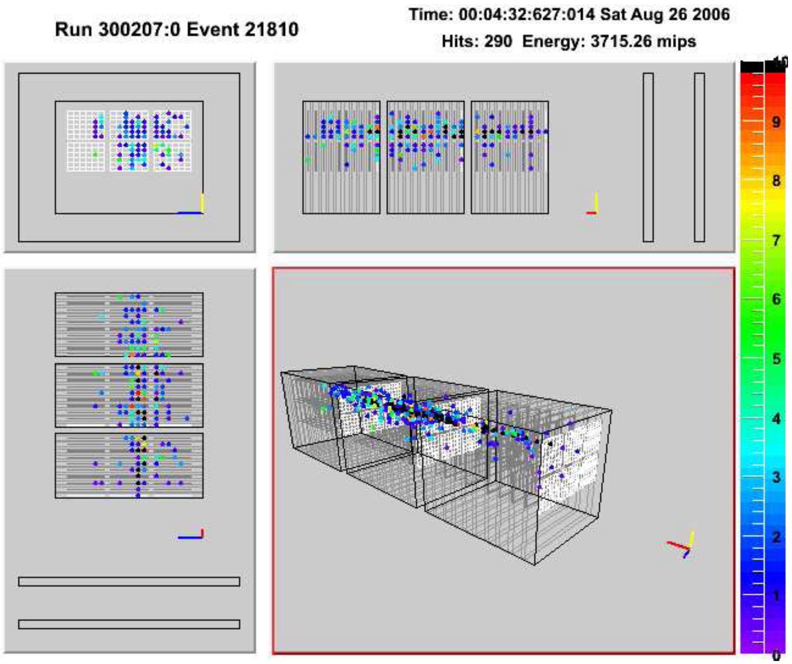
Yield : ~55% ok

some problems about gluing : chemical incompatibility with passivation, new passivation used
Crosstalk issue : see 2^{nd} part of this talk

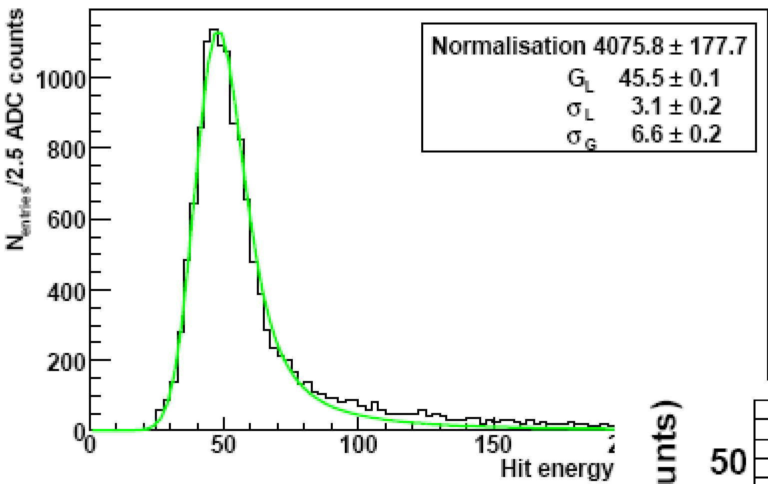
Test beam results

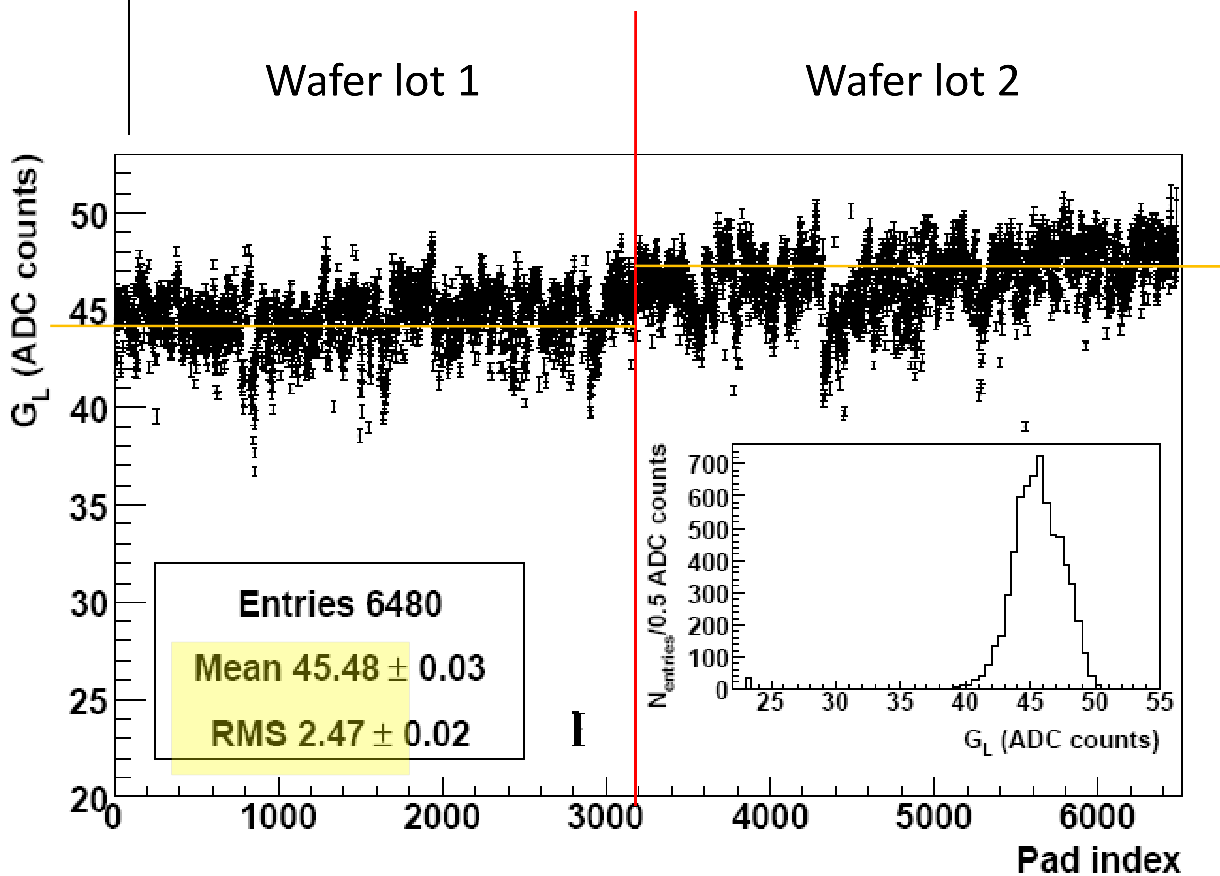
- Calibration constants
- Stability in time and temperature
- Uniformity
- Crosstalk between pixels



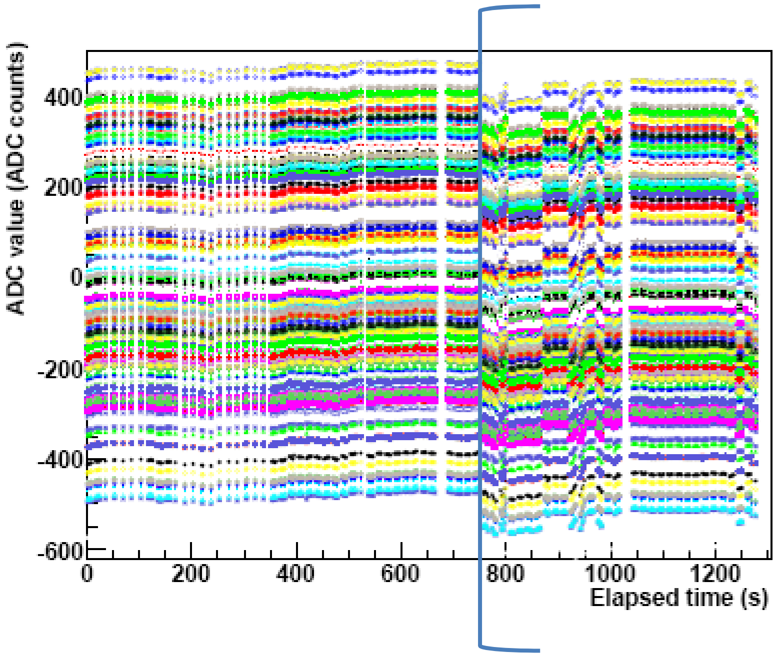


MIP Uniformity





Pedestal



Pedestals of 216 channels in the 24th layer as function of time

Change of bias point seen : pedestal shift due to power supply instability not compensated (fixed in next chip)

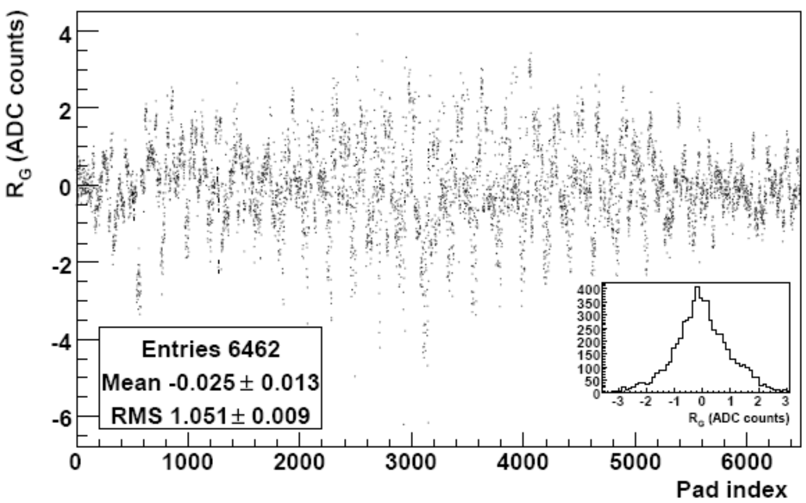
Residue < 0.2% MIP (test beam)

Channel to channel variations : 1.7 % MIP

Residual pedestal (test bench):

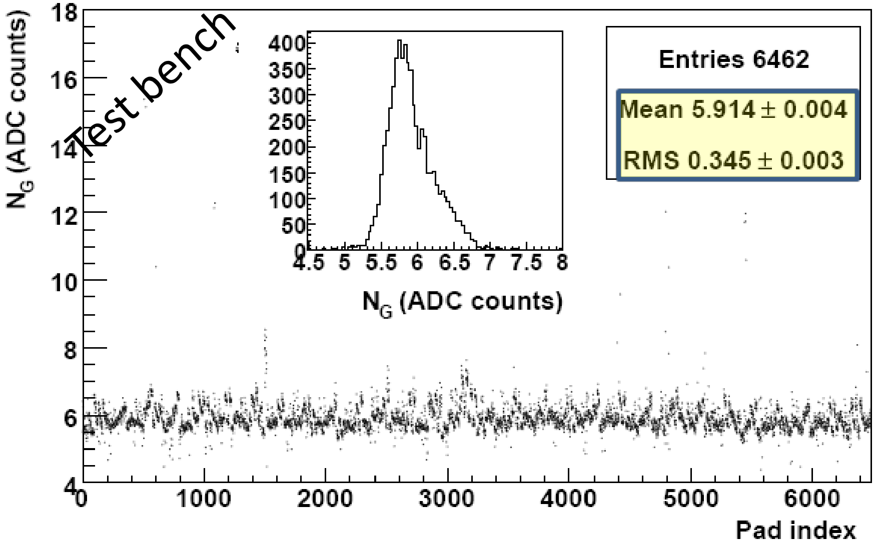
•Mean: -0.03±0.01 (ADC counts)

•RMS: 1.05±0.01



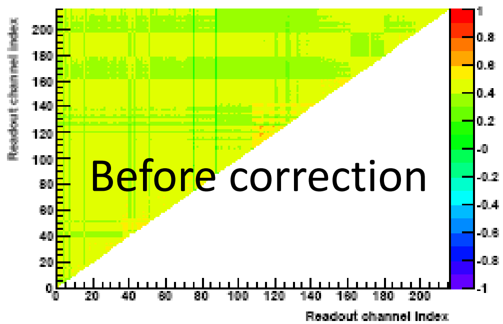
Pedestal can be corrected on an event by event basis to avoid pedestal shift

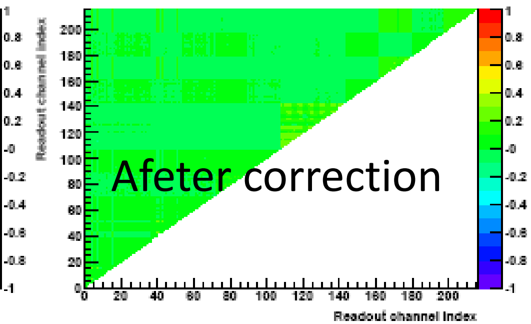
Noise (test beam)



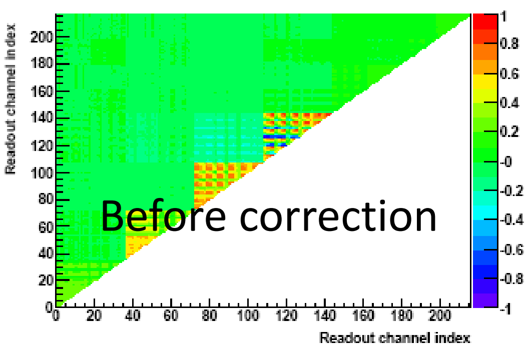
Signal/Noise = 7.63±0.01

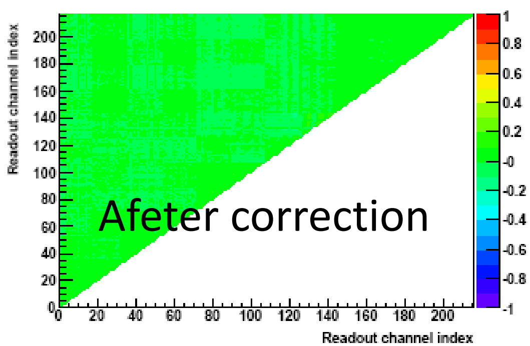
Target is 10 : a major part of the job is done until now!





In test beam, noise correlation between channels is 0.4207±0.0004 MIP (mean), 0.0551±0.0002 (stdev) before pedestal shift correction
and -0.0017±0.0003 (mean), 0.0519±0.0002 (stdev) after offline correction

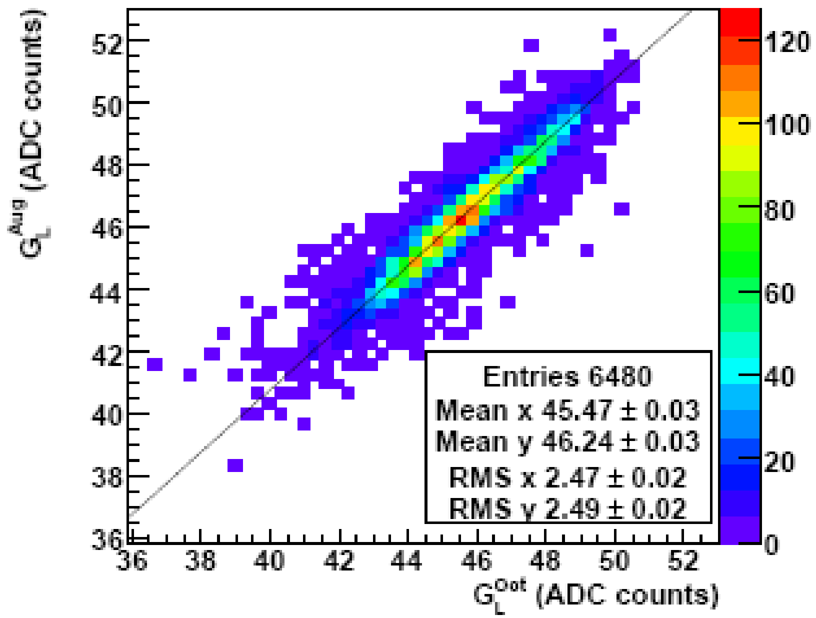




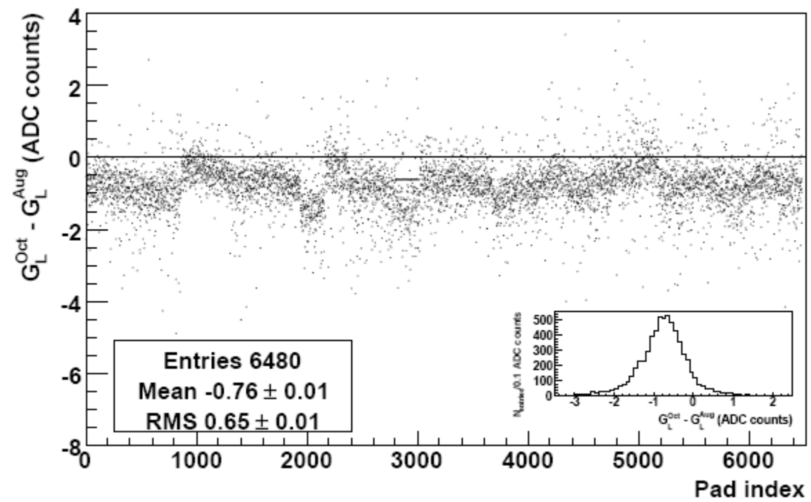
Coherent Noise (baseline shift) induced by signal was measured and can be corrected in the data.

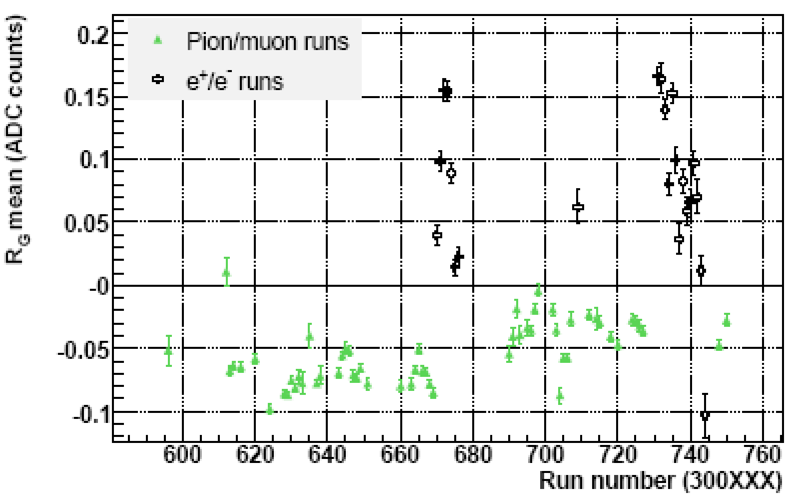
Time stability

MIP



August run vs. October run





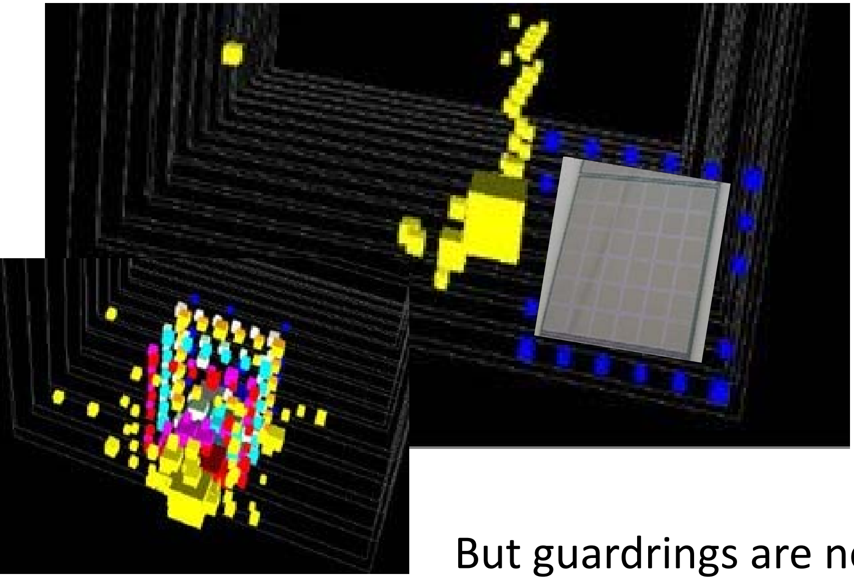
Pedestal run to run variations : 1.1±0.4 % MIP

Noise run to run variations : 2.00±0.03 % MIP

- More than 3% for 20% of channels
- But many different setup used

0.4% MIP with muons

Sensors : unexpected behaviour



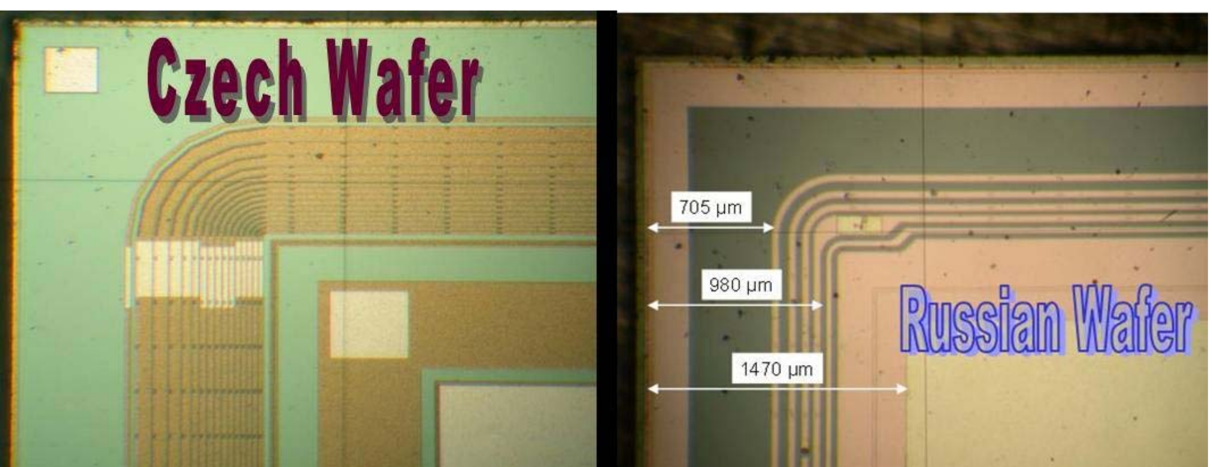
The square shape corresponds to guard-rings location

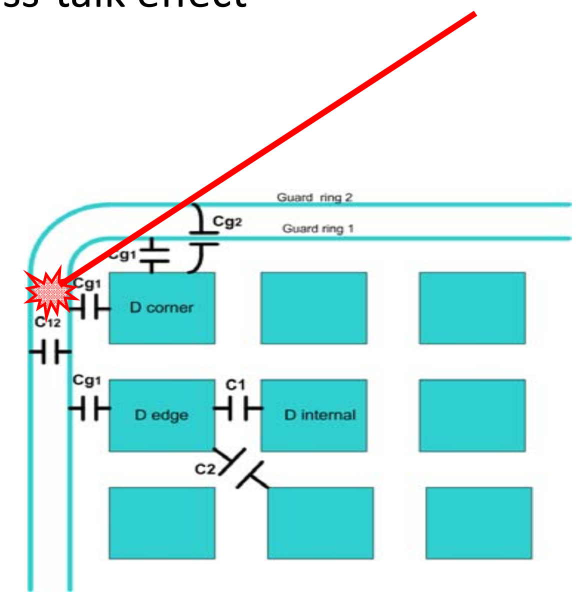
Effects of a particle hit on guard-rings could be propagated to every bordering pixels

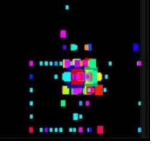
Unbiased guardrings act as a pad all around the sensor

= cross-talk effect

But guardrings are needed to avoid breakdown







Crosstalk hypothesis verification

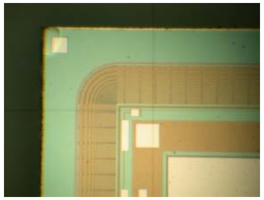
Square event issue must be solved with the cost issue in mind

Save production costs : minimize fabrication steps

Try segmented guardrings : capacitance in series along the guardring should reduce the signal propagation along the guardring

Simulate models of sensors

Electrical simulation
Silicon simulation



Try to reproduce the phenomenon on test bench

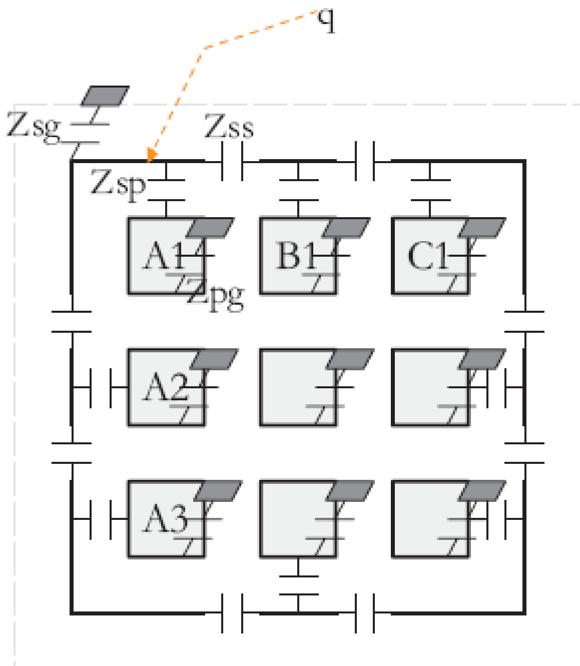
Printed circuit hardware model
Small real test sensors (OnSemi)

Compare results

Can be done for various topologies of the guardrings with different segment length and spacing

Analytic model of guarding crosstalk

Modéle pur guardrings



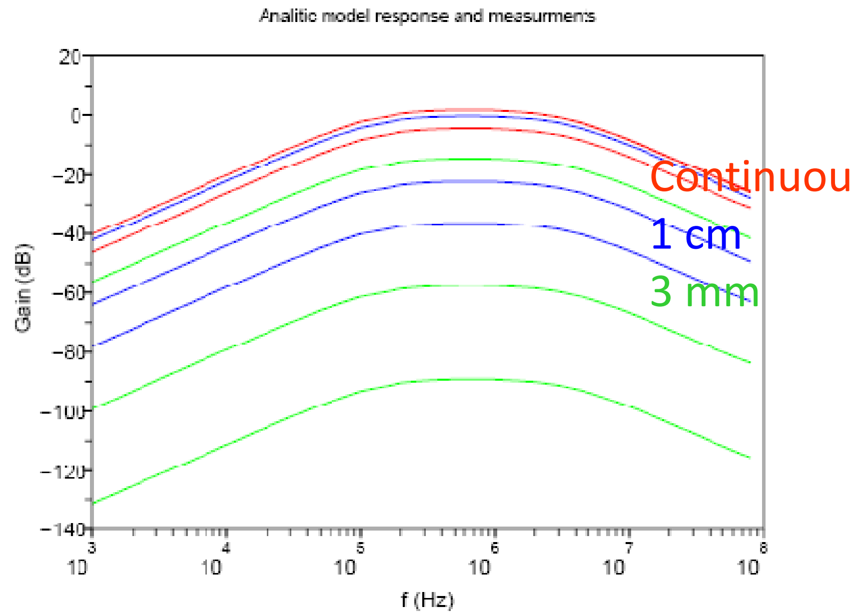


Figure 11: Model response (set for copper-epoxy model)

$$T = T_{elec} \times T_{pix} \times (T_{seg} \times T_{ss})^{N_{seg}} \times T_{seg} \times T_{inj}$$

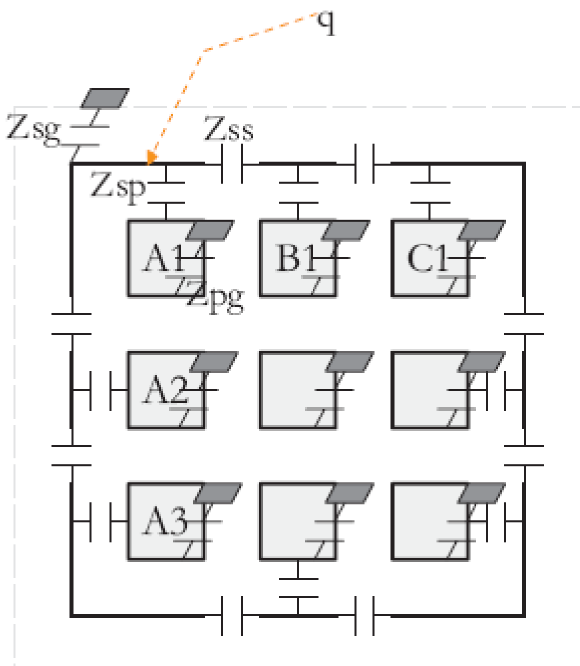
Measurement electronics — Crosstalk — Charge injector

Couplings are modeled with quadripoles filters
the number of segment Nseg appears

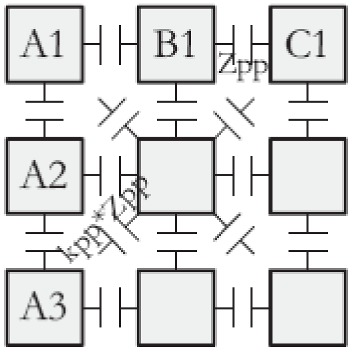
Pixel	Continuous	1 cm	3 mm
A1 (ref)	0	0	-14.5
A2	-6	-21.6	-75
A3	0	-34.6	-138

Includes the whole measurement chain (band pass filter)

Electrical simulation : SPICE



Pixel crosstalk		
0	-23.6	-46.6
-23.6	-37.5	-58.6
-46.6	-58.8	-72.3



+

Within the same simulation

=

Continuous			1 cm			3 mm		
0	-4.4	0	0	-18.3	-35.6	-11.5	-36.0	-49.8
-4.4	-14.1	-4.4	-18.3	-34.2	-51.2	-36.0	-49.0	-71.1
0	-4.4	0	-35.6	-51.2	-64.3	-49.8	-71.1	-85.7

dB

Guradring + pixel to pixel contribution to crosstalk are included

Copper-Epoxy hardware models

How to be confident in all these simulations ?

Investigate on segmented design without real wafers ! (first)

Continuous

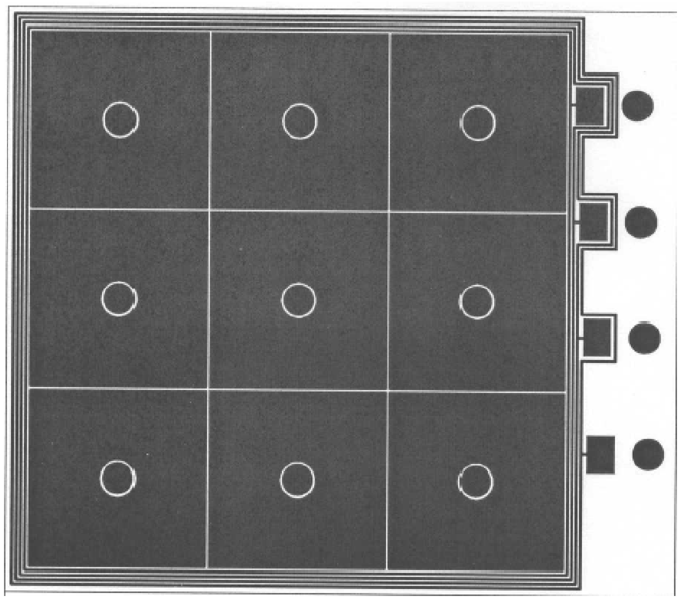
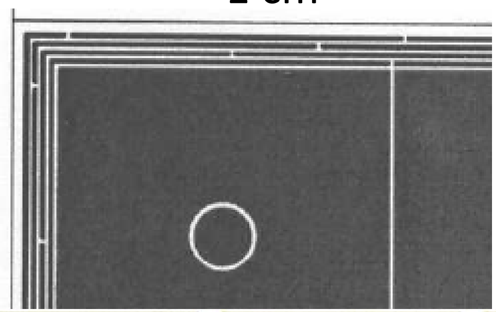
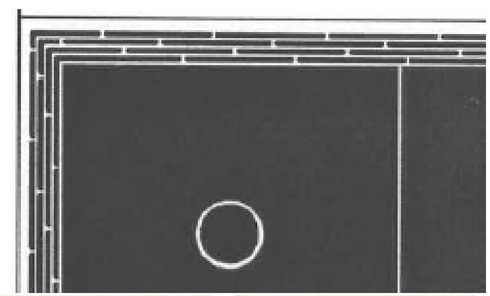


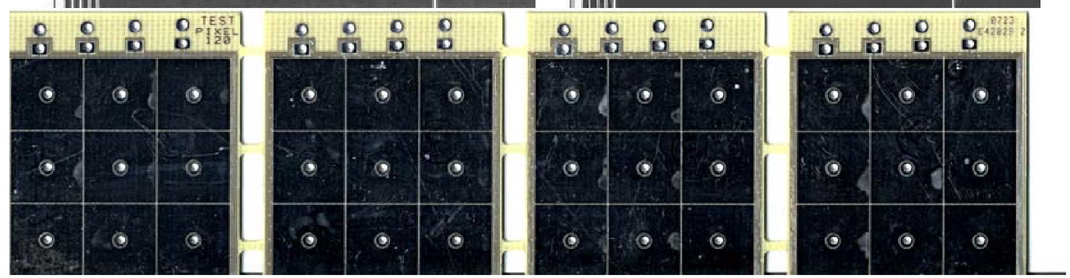
Figure 6: Copper epoxy made wafer model featuring 3x3 pixels and 4 continuous guardrings.

1 cm



3 mm

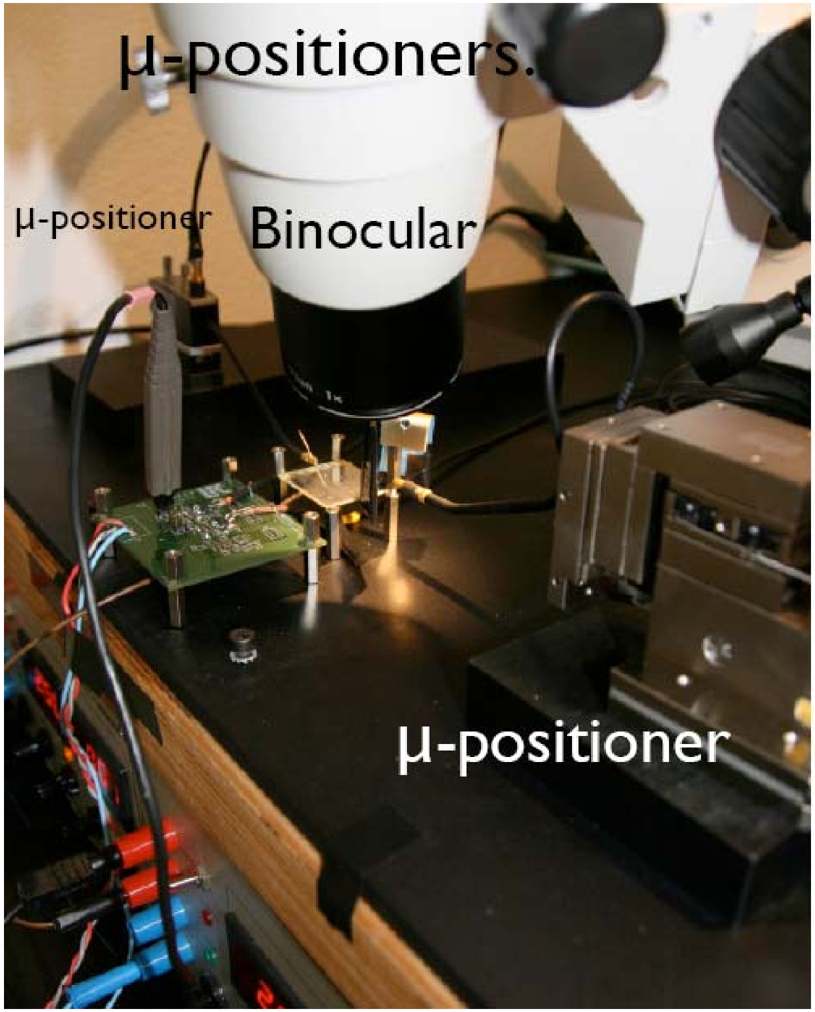


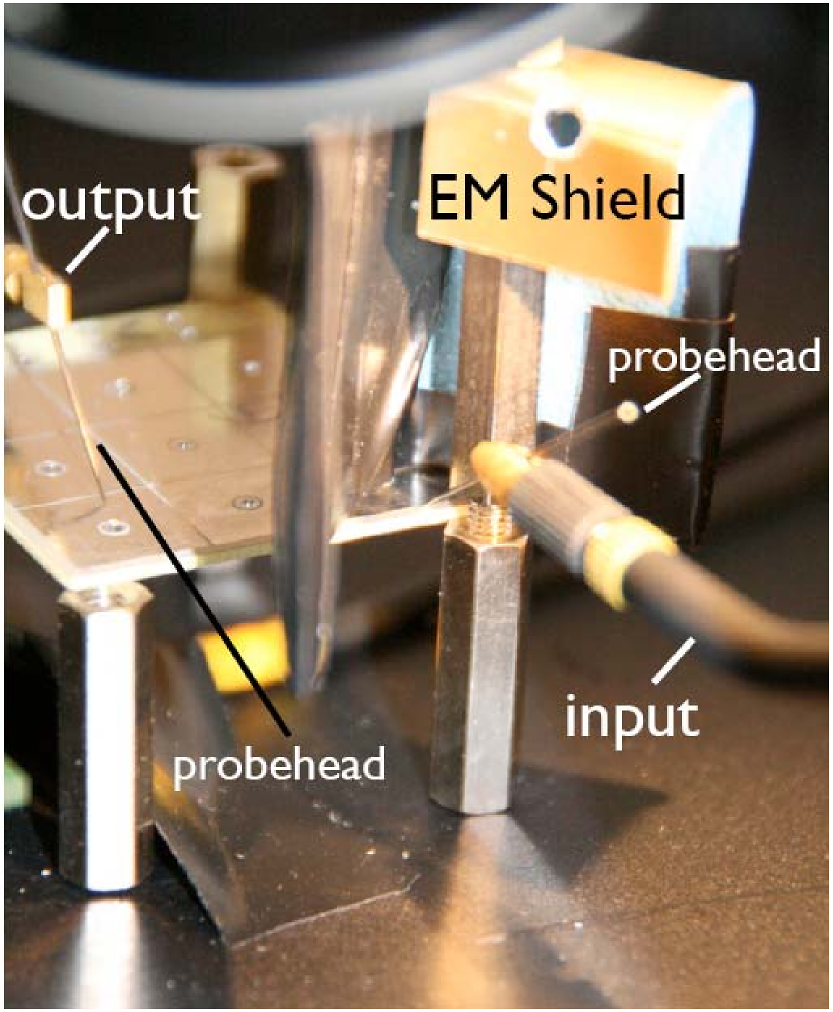


Then perform measurements on real wafers if the crosstalk hypothesis is verified

Test bench LPC

For crosstalk measurements on sensors (real or not)





M. Benyamna/R. Cornat/F. Morisseau

Measurements of printed circuit models

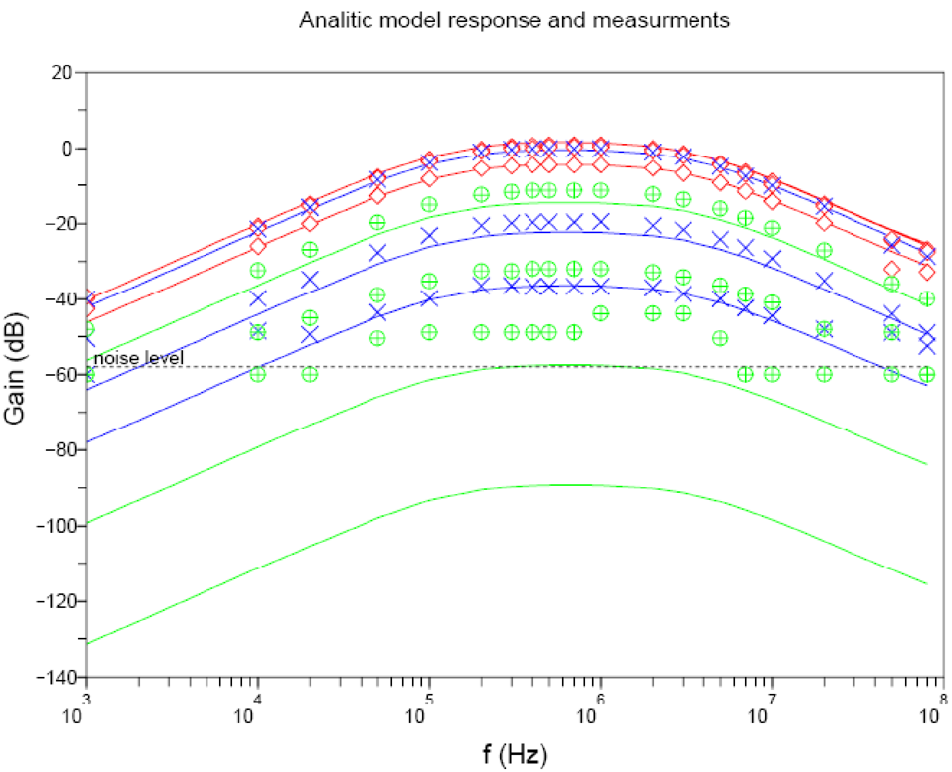
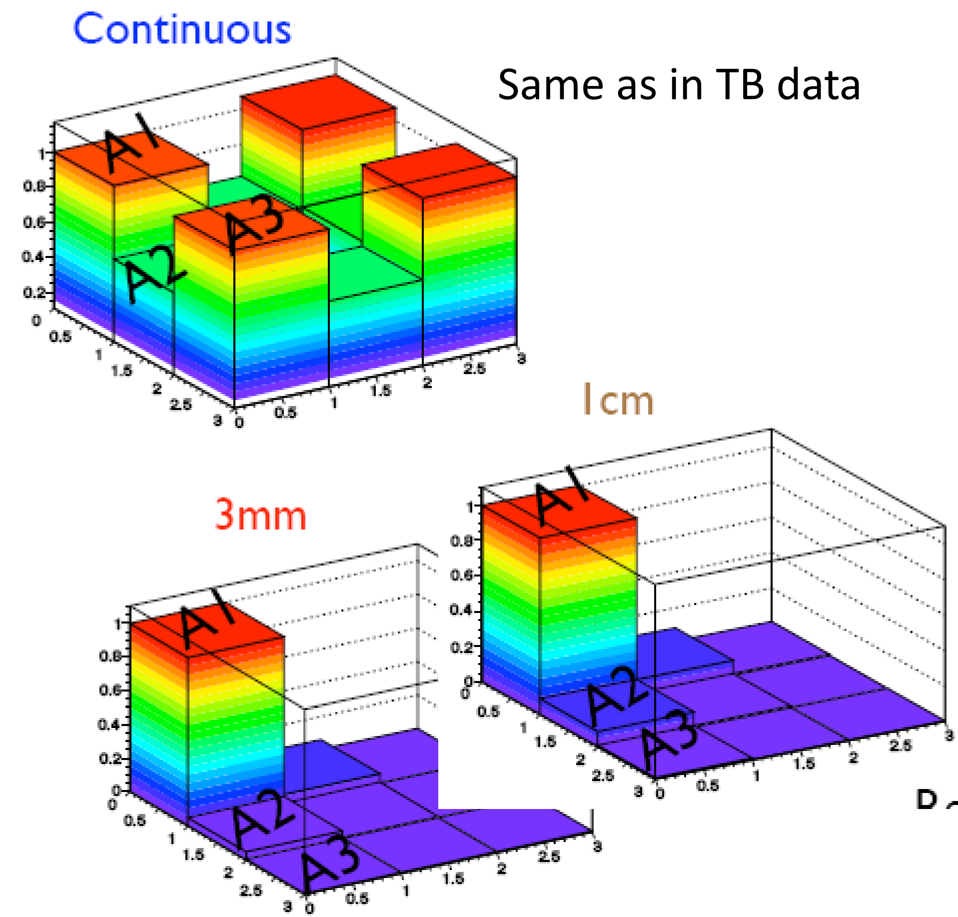


Figure 15: Model response and measurments made on hardware model



Raw data (no corrections applied) fit well with analytic model response

- Limited by noise level of measurement electronics (to be improved)
- Except for 3 mm segments

Conclusion on printed circuit models

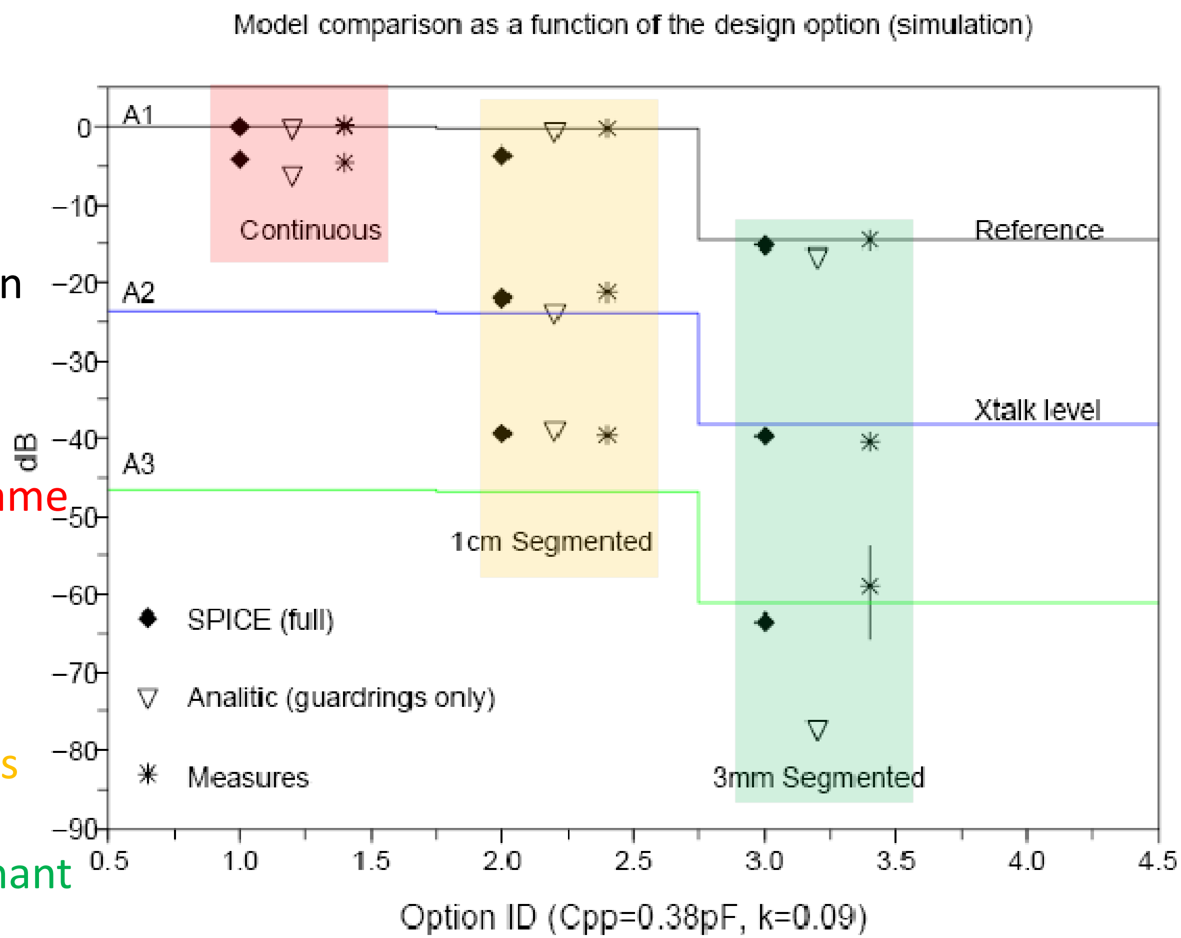
Electrical simulation includes :
•Guardring crosstalk
•Pixel to pixel crosstalk

Analytic model explains guardring related crosstalk
•Crosscheck Electrical simulation
•Gives expected contribution

Guardring crosstalk measured for continuous shape has the same behavior as in the TB data

Guardring and pixel to pixel crosstalk have the same contribution for 1cm segments

Pixel to pixel crosstalk dominant for 3mm segments



Segmented topology should limit square events effects to the pixel to pixel crosstalk

Extrapolation to real sensors

Name	First order formula	Set 1	Set 2	Set 3
Cpp		0.4 - 0.6 pF	0.8 - 1 pF	0.8 - 1 pF
Cpg	$\varepsilon_r \varepsilon_0 \cdot \frac{L_p^2}{W_t}$	4 - 5 pF	20 pF	33 pF
Csp		$\approx 60\, pF/m$	$\approx 80\, pF/m$	$\approx 80\, pF/m$
Csg	$\varepsilon_r \varepsilon_0 \cdot \frac{L_s * t_s}{W_t}$	0.06 pF/cm	0.1 pF/cm	0.17 pF/cm
Css		0.04 pF	0.1	0.1
k_{pp}		0.086	0.04	0.04

Table 3: Model parameters related to the geometry of the DUT and crosstalk coupling

First order formula to compute the parameters of the models

Si 500 µm

Continuous			1 cm			3 mm		
0	0	0	0	-21	-43	-11	-40	-68
0	0	0	-21	-42	-62	-40	-57	-83
0	0	0	-43	-62	-80	-68	-83	-98

Si 300 µm

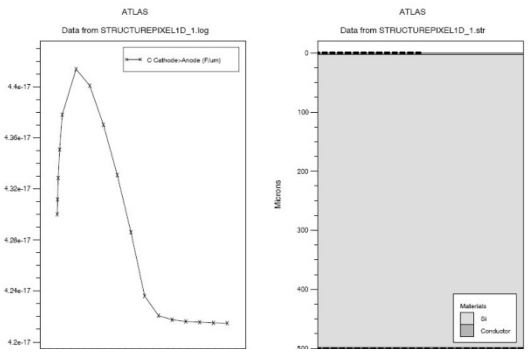
Continuous			1 cm			3 mm		
0	0	0	0	-20	-37	-4	-36	-67
0	0	0	-20	-44	-58	-36	-56	-85
0	0	0	-37	-58	-70	-67	-85	-103

Same trend as for printed circuit boards

But simulations assume a local hit : what if multiple hits (EM shower) ?

Are guardrings still act as guardrings (protection against breakdown) when segmented ?

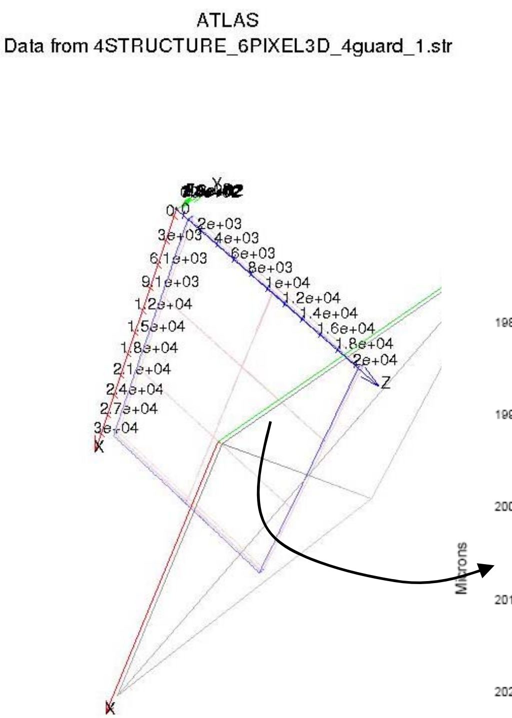
Silicon Simulation

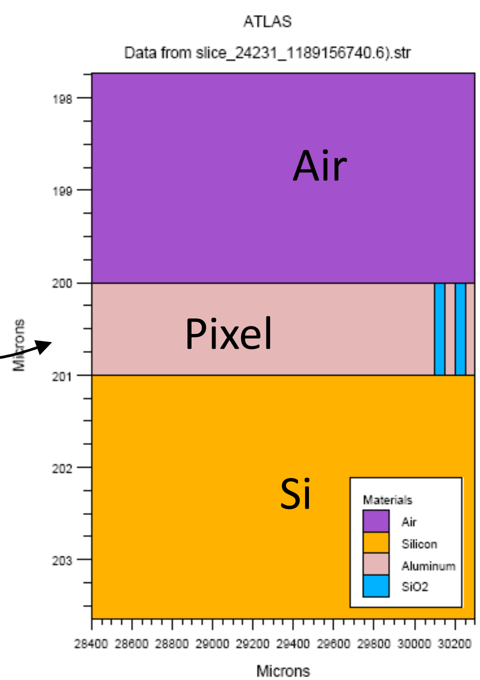


First step to check capacitance values between pixels, guardrings, substrate

Then back annotate to SPICE simulation

Simulated Cap. Values are within a 20% range from expected values calculated with first order formula





3D simulation are ongoing to take into account border effects

Second step to verify if guardrings still act as guardrings…

Conclusion

A large ECAL prototype : 10 000 channels

- Highly granular
- Compact

Signal/Noise = 7.63±0.01

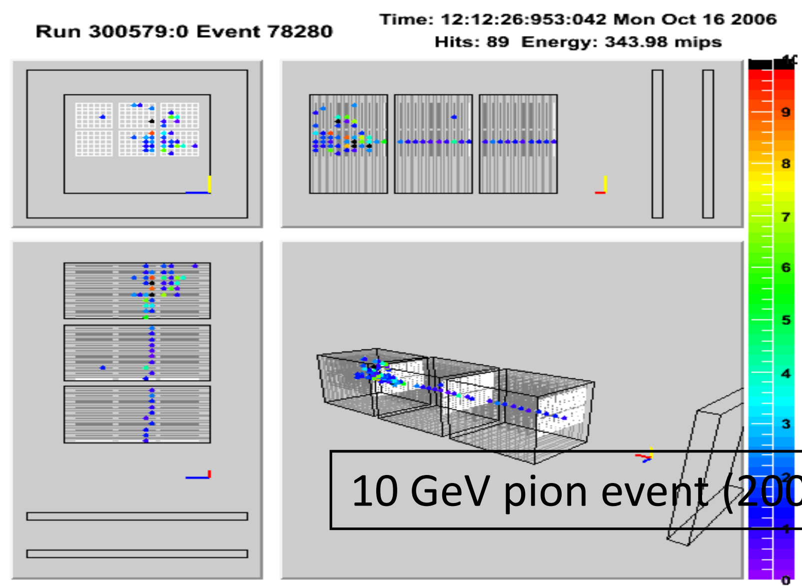
Target is 10 : a major part of the job is done until now!

High amount of data accumulated from test beam

Prototype is qualified

Next generation is being designed

- 4x Higher granularity (0.25 cm2 pads)
- Larger sensors (18x18 cm2)
- Wider volume and stringent constraints on mechanics
- New ASIC chips embedded in PCB



10 GeV pion event (2006)

On going work on sensors

Floating guardring geometry to be tested on real sensors very soon