# MAPS Report

## Work-package 3

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## Outline

1. Design of the first sensor
   - Pixel architectures
   - Test structure
   - Sensor simulation
2. Sensor testing
   - Laser setup
   - Source setup
   - Beam test setup
3. Analysis of beam test data
   - Troubleshooting
   - Tracking efficiency
   - MC simulation

# What does MAPS stands for ?

- Monolithic Active Pixel Sensor:
  - CMOS technology, in-pixel logic: pixel=sensor+readout electronics,
  - 50x50 $\mu m^2$ : reduces probability of multiple hit per pixel,
  - 4 diodes per pixel: collection of charge mainly by diffusion,
  - 0.18 $\mu$m INMAPS process to optimise charge collection.
  - binary readout: in-pixel comparator with adjustable threshold,
  - each pixel can be masked individually,
- MAPS-ECAL : swap-in solution to the standard Si-W ECAL.

# Why for a calorimeter ?

- ☺ high granularity :
  - better position resolution → potentially better PFA performances,
  - or detector more compact → reduced cost.
- ☺☹ $10^{12}$ pixels : digital readout, DAQ rate dominated by noise
- 😐 Area needed for logic and RAM : 10% dead area
- ☺ Cost saving : CMOS vs high resistivity Si wafers
- ☺ Power dissipation : more uniform
- ☹ challenge to match analog ECAL 1 $\mu$W/mm$^2$

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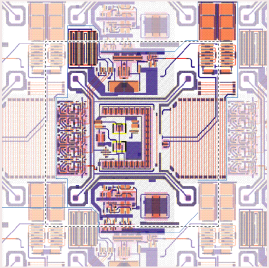
# Sensor designs
## Two architectures

- 4 diodes, $\varnothing 1.8\ \mu$m
- common comparator+readout logic
- 2 types of capacitors for each architecture

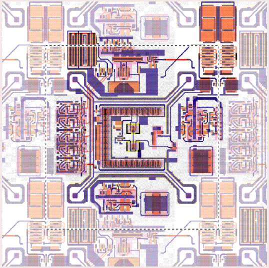
### Pre-shaper design

Big resistor

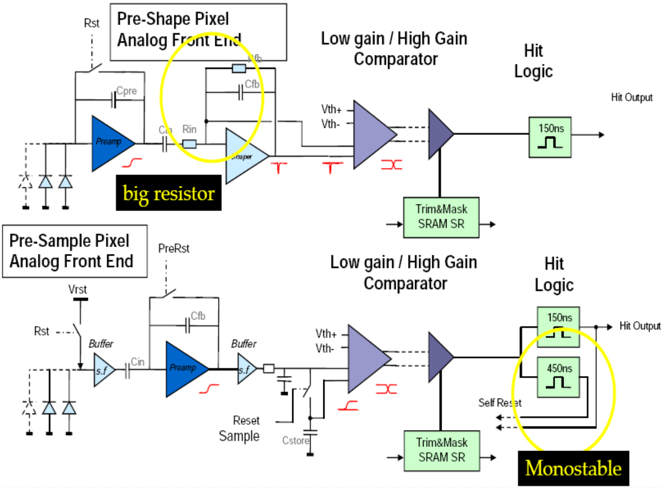


### Pre-sampler design

Monostable, self-reset



# Sensor designs schematics

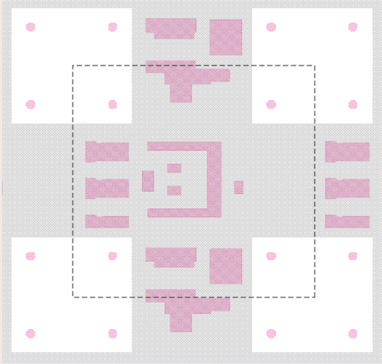


# The INMAPS process

## Objective: shield the electronics n-well

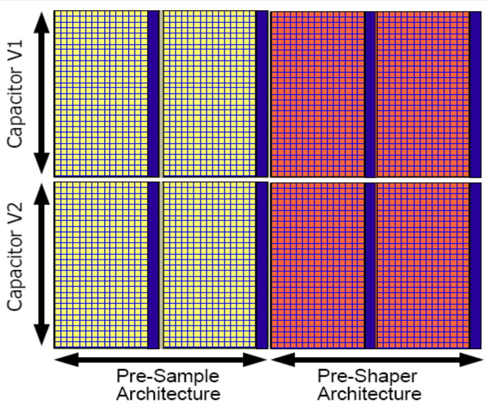
pink : electronics n-well, eating charge

grey : deep p-well implant 1 $\mu$m thick added to block the charge absorption

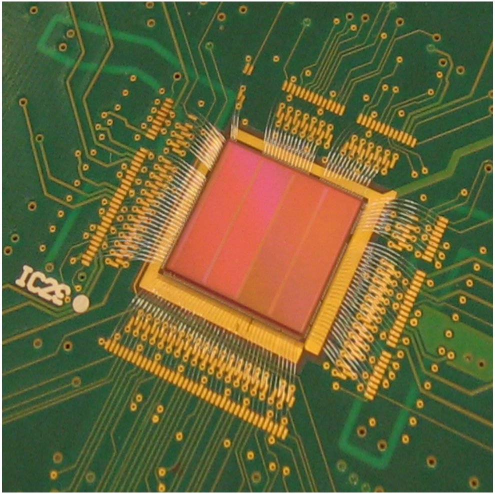


# Sensor architecture overview

## 1 × 1 $cm^2$ in total, 8.2 million transistors, 28224 pixels



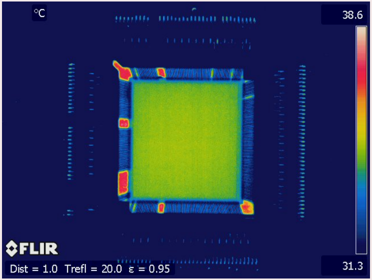
# Sensor 1 bonded

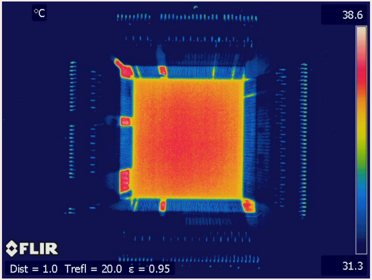


# Uniformity of power dissipation

## Thermal images

Around the pixels: bond wires (in blue) and ground pads (in red).

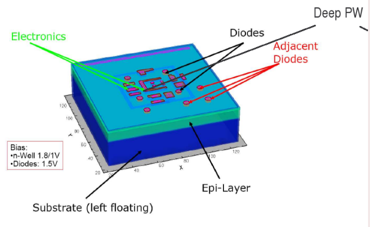


# Sensor simulation

## Software used

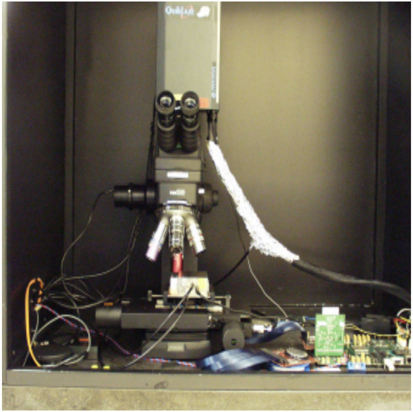
Sensor simulation: Centaurus TCAD,
Pixel description: CADENCE GDS file.




- Diode size has been optimised in term of signal over noise ratio, charge collected in the cell in the worse scenario (hit at the corner), and collection time.
- Diodes place is restricted by the pixel designs, e.g. to minimise capacitance effects

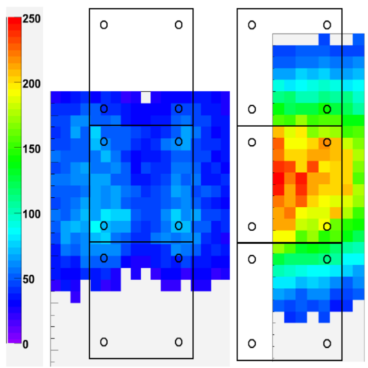
# Outline

# Laser test setup



## Analogue test structure

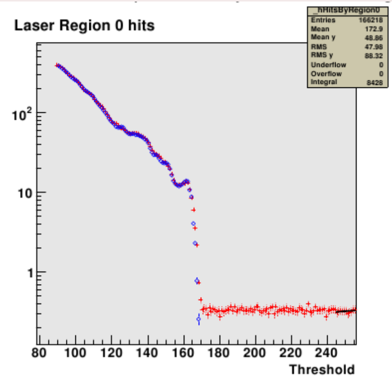
No INMAPS (left) vs INMAPS (right).

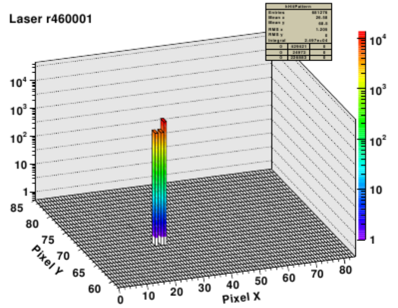


# Threshold scan with and without laser

## blue: without laser, red: with laser on

The laser was fired in pixel x≃25, y≃69 (right plot).



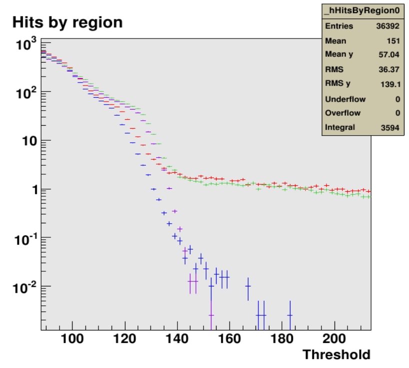
# Source test setup : $\beta$ source

## $^{90}Sr$ or $^{204}Tl$

Number of hits per region vs threshold.

No source: blue and purple

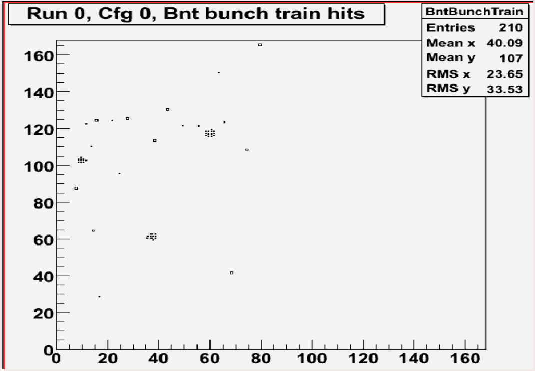
Source : red and green



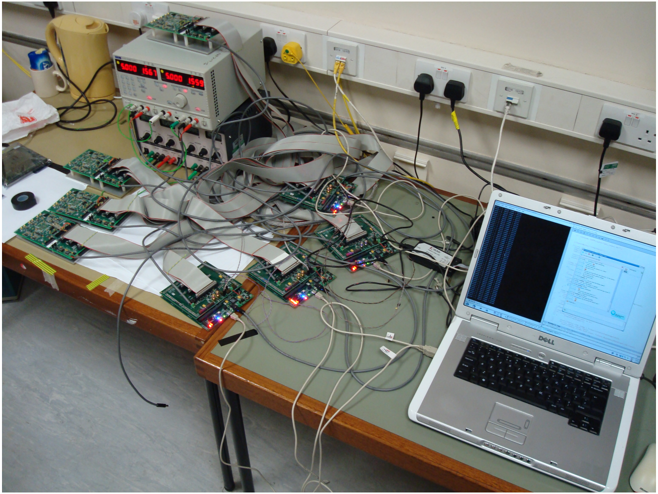
# Source test setup : $\alpha$ source

## $^{241}$Am

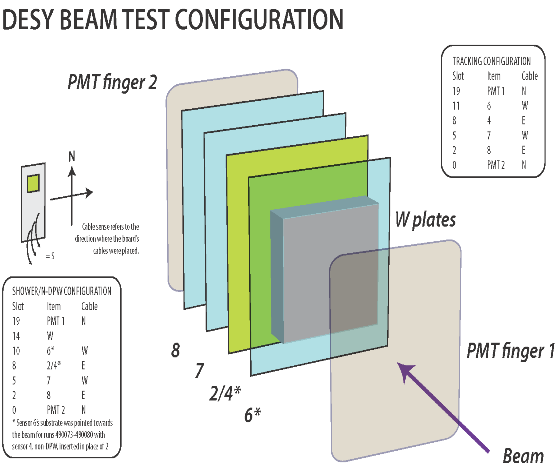
x-y axis: pixel index.



# Preparing for the beam test at DESY

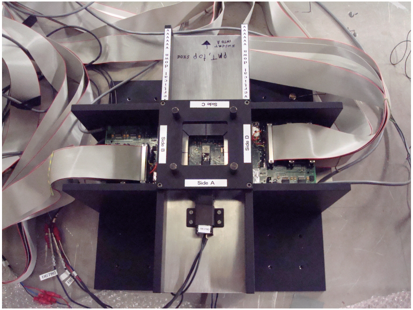


# Installation at DESY

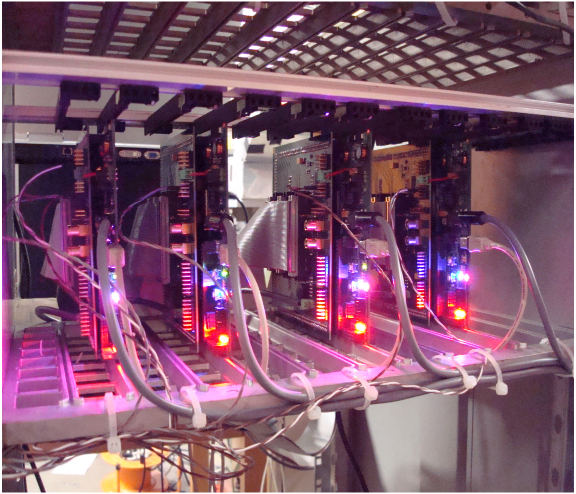


# Four layers inserted in their stand

... and a lot of cables !!



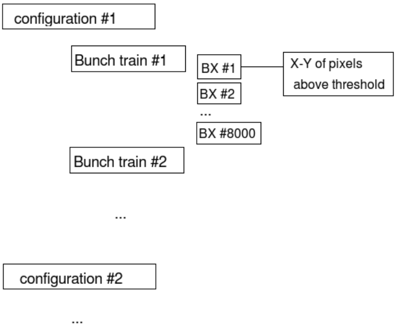

# DAQ boards all working



# Structure of data taking

## Configurations:

- With one sensor : threshold scan. Threshold unit = TU → random unit: need gain to convert into MIPs.
- With 4 sensors: 3 sensors at nominal threshold, last one threshold scan. Nominal threshold should be set so that worse case S/N=10.



# Summary of the data taken

| Shower studies | | | |
|---|---|---|---|
| Type | E (GeV) | W (mm) | bunch trains (k) |
| nominal threshold 150/300 TU | no beam | 30 | 134 |
| nominal threshold 150/300 TU | 6 | 30 | 306 |
| threshold scan | 6 | 30 | 1000 |
| nominal threshold 150/300 TU | 6 | 15 | 20 |
| nominal threshold 150/300 TU | 6 | 9 | 40 |
| nominal threshold 120/200 TU | 6 | 9 | 40 |
| nominal threshold 120/200 TU | no beam | 9 | 40 |
| threshold scan (1 sensor w/o deep p-w) | 3 | 9 | 879 |
| threshold scan (1 sensor w/o deep p-w) | no beam | 9 | 435 |

| Efficiency studies | | | |
|---|---|---|---|
| threshold scan | 3 | 0 | 3300 |
| threshold scan | no beam | 0 | 406 |
| threshold scan (1 sensor w/o deep p-w) | 3 | 0 | 531 |
| threshold scan (1 sensor w/o deep p-w) | no beam | 0 | 403 |

# Outline

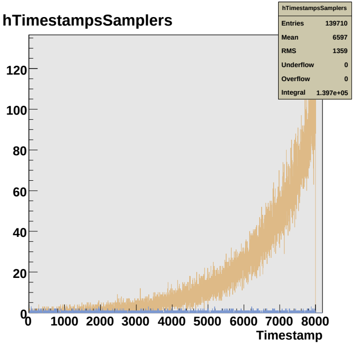
# Finding the working point is not trivial ...

- A few critical issues have been identified that prevented the sensor from working, and are now worked around.
- Predicted signal/noise of $\simeq$10 worse case (corner of a pixel).
- Working point is not yet understood:
  - Gain is a priori a factor 2 too low for the samplers.
  - Noise is a priori a factor 5 too high for the samplers.
  - With 31 references to play with : hard work to scan everything !!
- Working point at DESY was at the best of our understanding in December.
- No shower studies in the following.

# A few additional difficulties ...

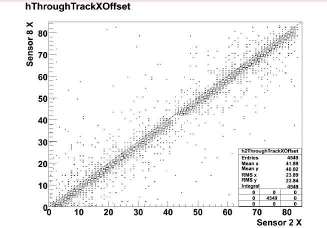
- Two pixels architectures (shapers/samplers) alternated in the four layers: one track = 2 samplers + 2 shapers.

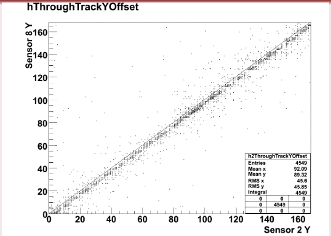
- Memory filling: per region and per row : $\leq$ 19 groups per bunch train. One noisy pixel: entire row (42 pixels) “dead” for the entire bunch train.
- Samplers less understood. E.g. reset after firing only $\rightarrow$ noise divergence $\rightarrow$ noise (and hence sensitivity) increases with time.
- Since DESY, we realised that the non-uniformity of the pedestals is non-negligeable compared to our best knowledge of a MIP: $\simeq$100 TU.



# Sensor is however responding !

## Spatial correlations in x and y: sensor #8 vs sensor #2



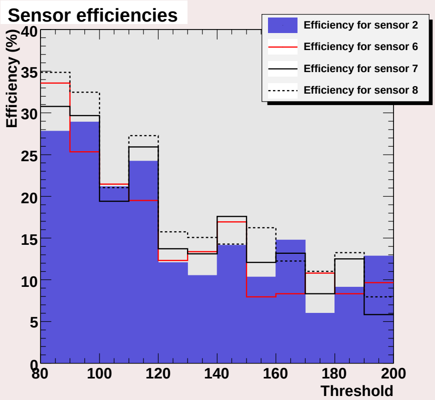

## Since DESY we realised...

- Non-uniformity not negligeable compared to our best knowledge of a MIP: $\simeq$100 TU.
- Preliminary studies show narrow noise pixel-by-pixel: $\simeq$5 TU,
- but wide pedestal distribution.
- Not compensating this effect $\rightarrow$ artificially high noise.

# Tracking efficiency

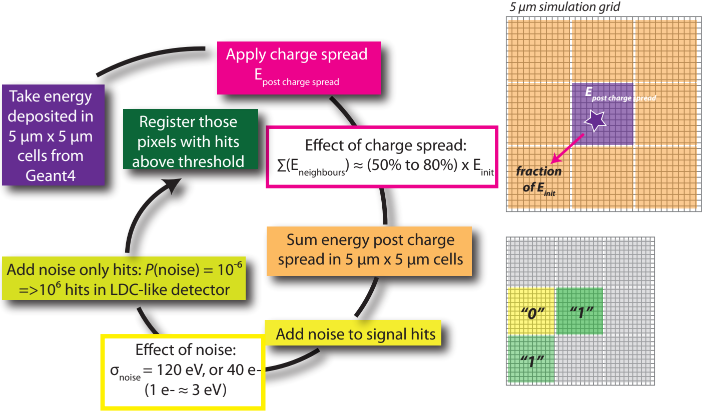
- Without individual threshold settings: noise artificially large ≃25 TU.
- Threshold scan restricted around the "nominal" settings at DESY: 120 (shapers)/200 (samplers) TU.

- Tracks done with 3 layers: efficiency of the $4^{th}$ layer to give a hit with a good $\chi^2$.
- $\chi^2$ cut: noise is completely removed !
- To have "real" efficiency, need to measure each pixel and adjust threshold setting accordingly !



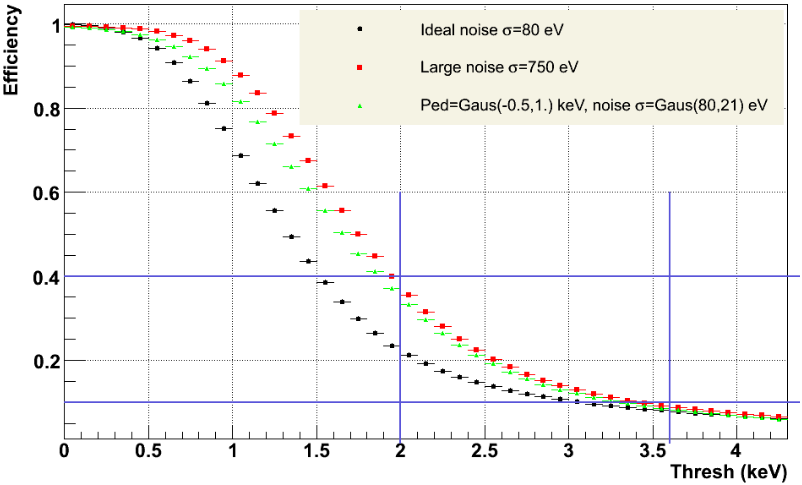
# MC simulation of beam test setup

## Digitisation procedure



# MC: threshold scan with different scenarios

Between blue lines: estimated corresponding data scan region.



# Conclusion

- Power dissipation is confirmed to be uniform.
- INMAPS process makes a huge improvement in the amount of charge collected
- Shapers are more stable, uniform in time, and easier to understand, for similar performances.
- Complex sensor:
  - 8 million transistors,
  - pixels threshold individually adjustable,
  - 31 references to adjust...

  → Time needed to understand it!
- Beam test at DESY: too early in our understanding of the sensors, but still lots learnt from the data.
- Non-uniformity in threshold settings not accounted for yet: individually adjusted settings required.

# Outlook

- Gain measurements: laser setup on its way to perform a full scan and measure individual pixel response:
    - Check geometrical mapping,
    - measure response uniformity and gain,
    - evaluate charge spread: comparison with sensor simulation.
- Another beam test if possible, with correct adjustment of individual pixel threshold.
- Design of the second round: correction of known features + further development if time/money allows.


Thank you for your attention !

(It's better to concentrate its intelligence on messed-up things than messing up on intelligent things.)