A MAPS-based digital Electromagnetic Calorimeter for the ILC

Anne-Marie Magnan
Imperial College London

on behalf of the MAPS group:
Y. Mikami, N.K. Watson, O. Miller, V. Rajovic, J.A. Wilson
(University of Birmingham)
J.A. Ballin, P.D.Dauncey, A.-M. Magnan, M. Noy
(Imperial College London)
J.P. Crooks, M. Stanitzki, K.D. Stefanov, R. Turchetta, M. Tyndel, E.G. Villani
(Rutherford Appleton Laboratory)

CALICE
Calorimeter for LC

Layout

Context of this R&D

I. Introduction to MAPS
   - What is MAPS ?
   - Why for an Electromagnetic CALorimeter ?

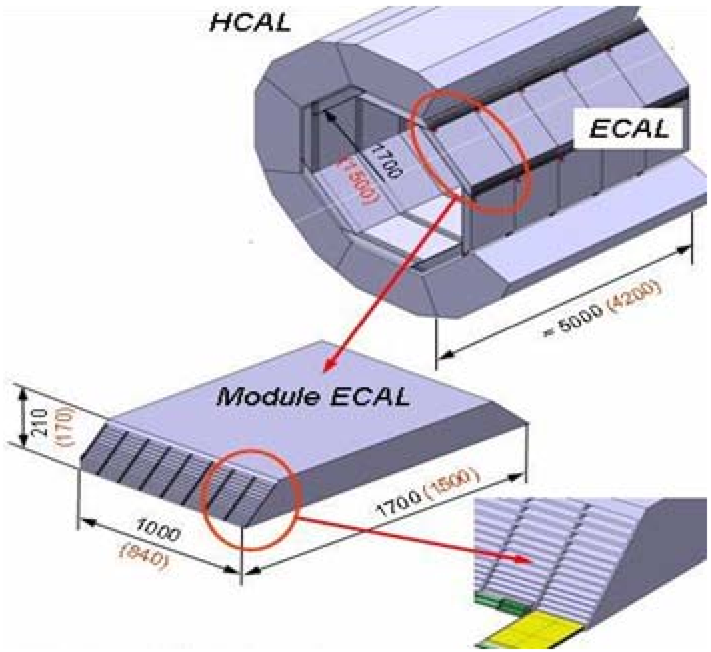
II. The current sensor layout

III. Sensor simulation

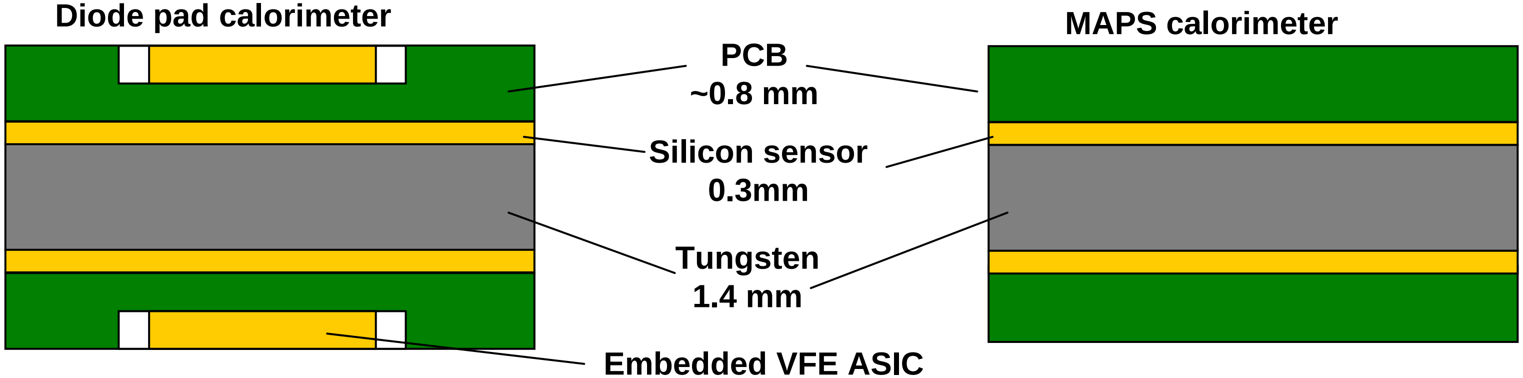
IV. Physics simulation
   - digitisation procedure
   - influence of parameters on the energy resolution

Conclusion

Context of this R&D

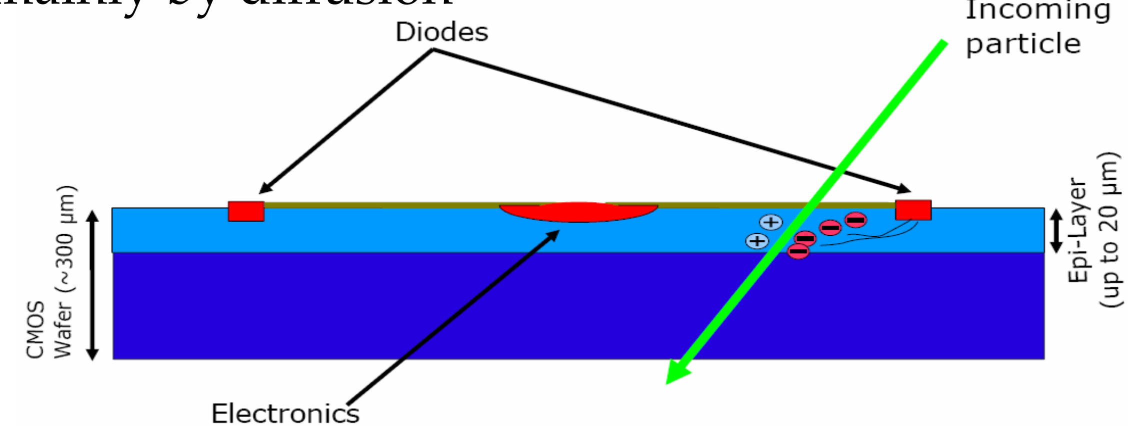


- Alternative to CALICE Si/W analogue ECAL
- No specific detector concept
- "Swap-in" solution leaving mechanical design unchanged



Introduction to MAPS

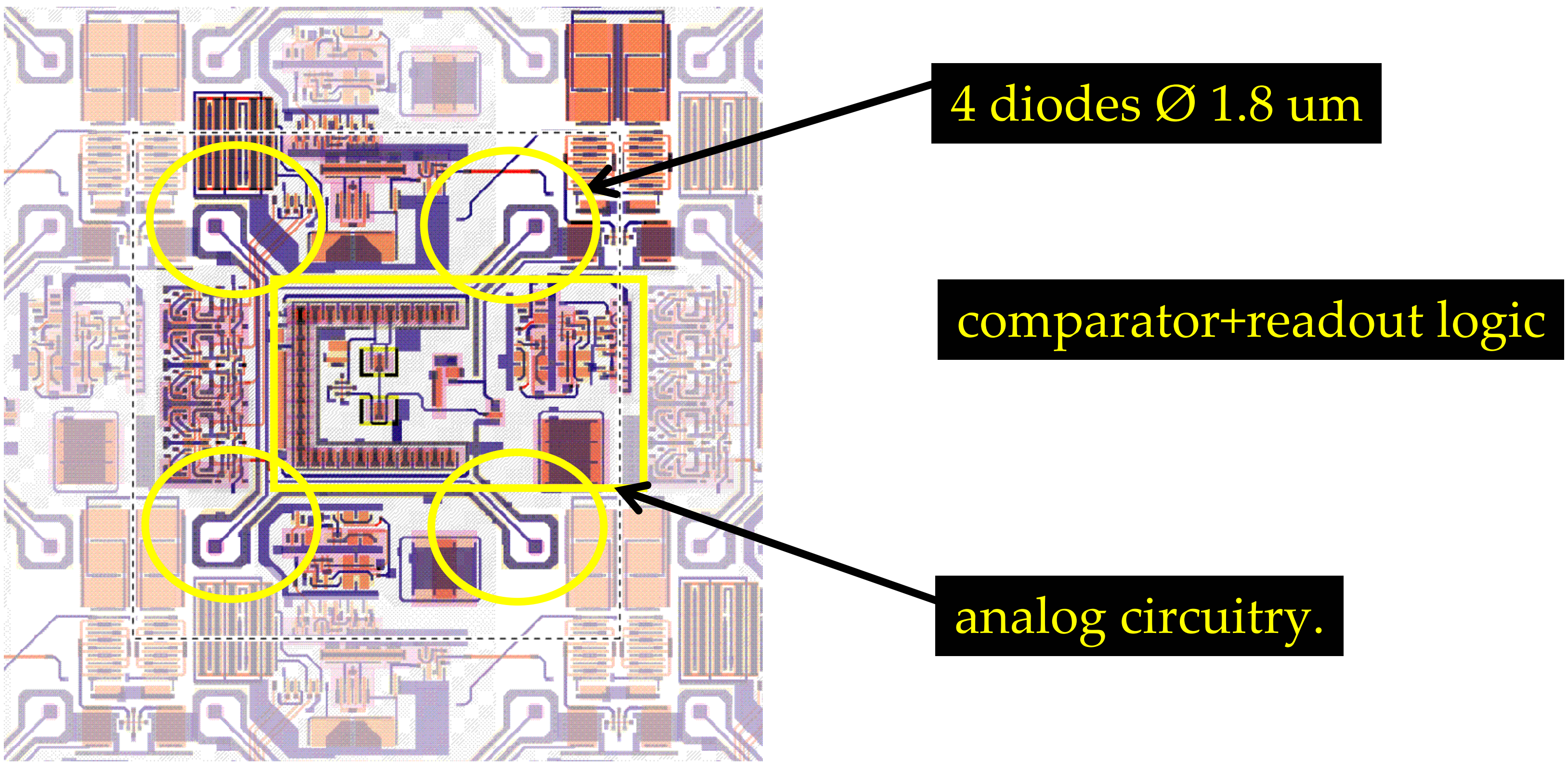
- MAPS ? Monolithic Active Pixel Sensor
  - ✓ CMOS technology, in-pixel logic: **pixel=sensor+readout electronics**
  - ✓ **50x50 μm²** : reduces probability of multiple hit per pixel
  - ✓ Collection of charge mainly by diffusion



- Why for a calorimeter ?
  - **<u>high granularity</u>** :
    - ☺ 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
  - **<u>Cost saving</u>** : ☺ CMOS vs high resistivity Si wafers
  - **<u>Power dissipation</u>** : ☺ more uniform
    ☹ challenge to match analog ECAL 1 μW/mm²

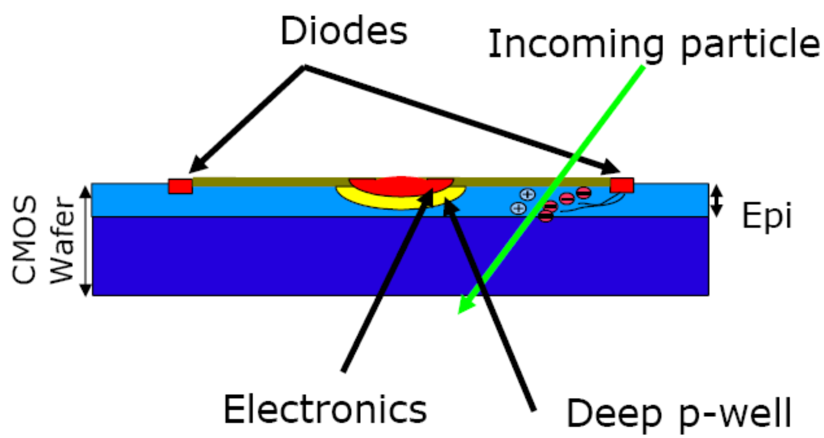
Sensor layout : v1.0 submitted !

<u>Design submitted April 23rd</u>, with several architectures.
One example:

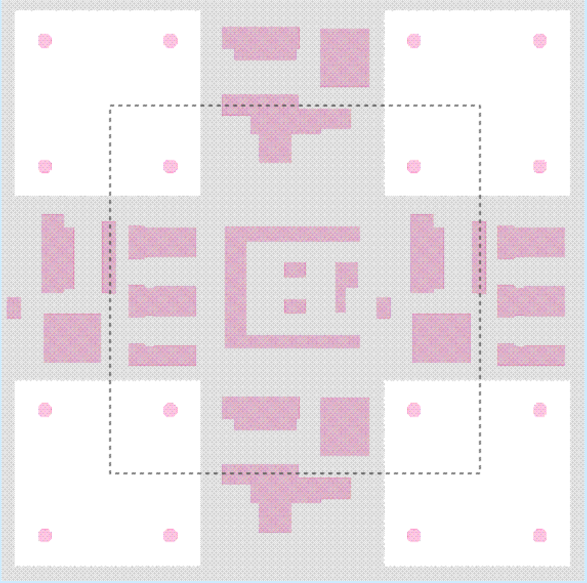


What's eating charges : the N-well and P-well distribution in the pixels

- Electronics N-well absorbs a lot of charge : possibility to isolate them ?
- INMAPS process : deep P-well implant 1 μm thick everywhere under the electronics N-well.

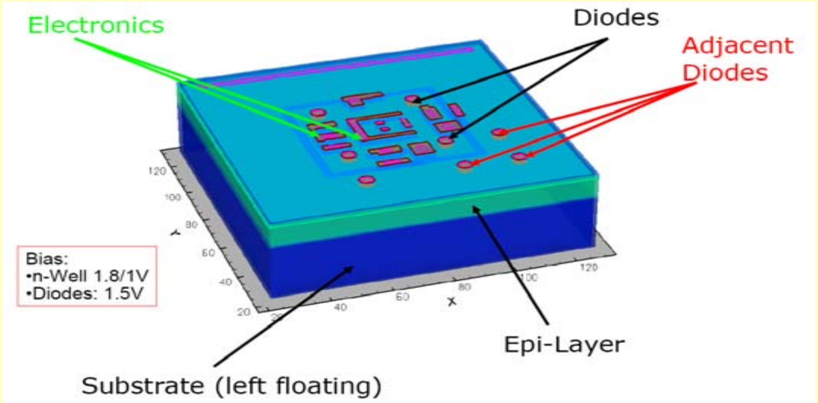


pink = nwell (eating charge)
blue = **deep p-well added to block the charge absorption INMAPS process**



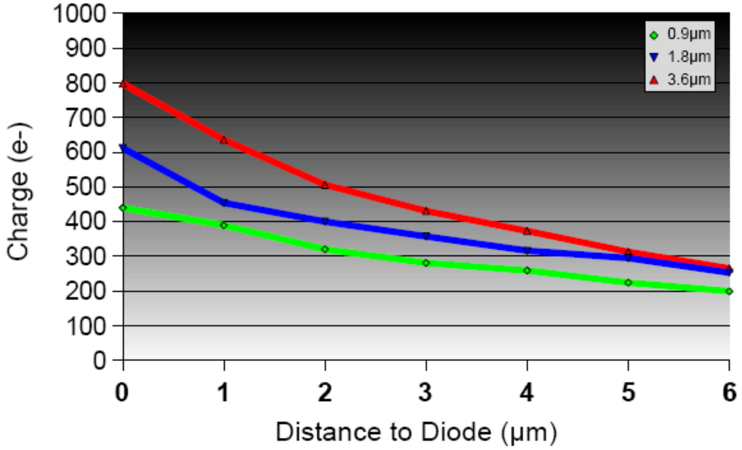
The sensor simulation setup

Using Centaurus TCAD for sensor simulation + CADENCE GDS file for pixel description



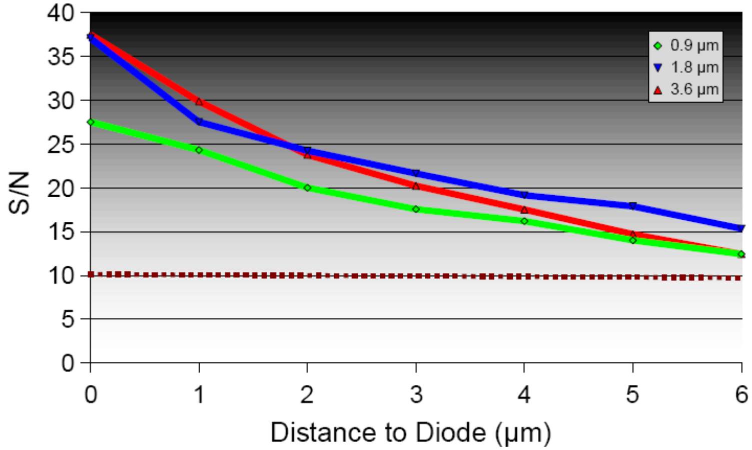
- Diode size has been optimised in term of signal over noise ratio, charge collected in the cell in the worse scenario (hit at the corner), and collection time.
- Diodes place is restricted by the pixel designs, e.g. to minimise capacitance effects

Collected charge



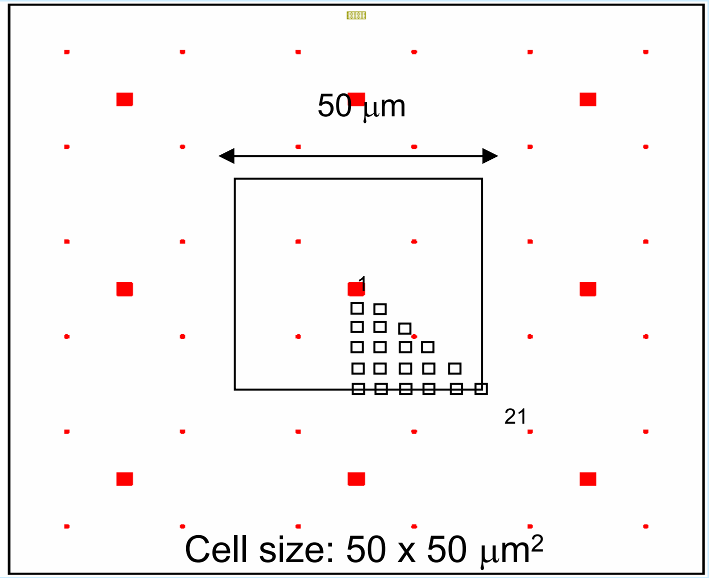
0.9 μm
1.8 μm
3.6 μm

Signal over noise

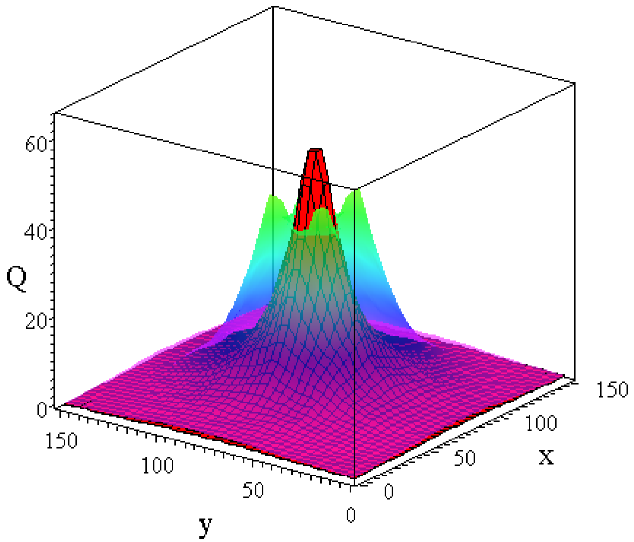


Fast simulation for Physics analysis

Preliminary results obtained assuming perfect P-well : to reduce the computational time, no N-well or P-well are simulated. Will be compared to a pessimistic scenario with no P-well but a central N-well eating half of the charge.



Whole 3*3 array with neighbouring cells is simulated, and the initial MIP deposit is inputted on 21 points (sufficient to cover the whole pixel by symmetry)



Example of pessimistic scenario of a central N-well eating half of the charge

Physics simulation

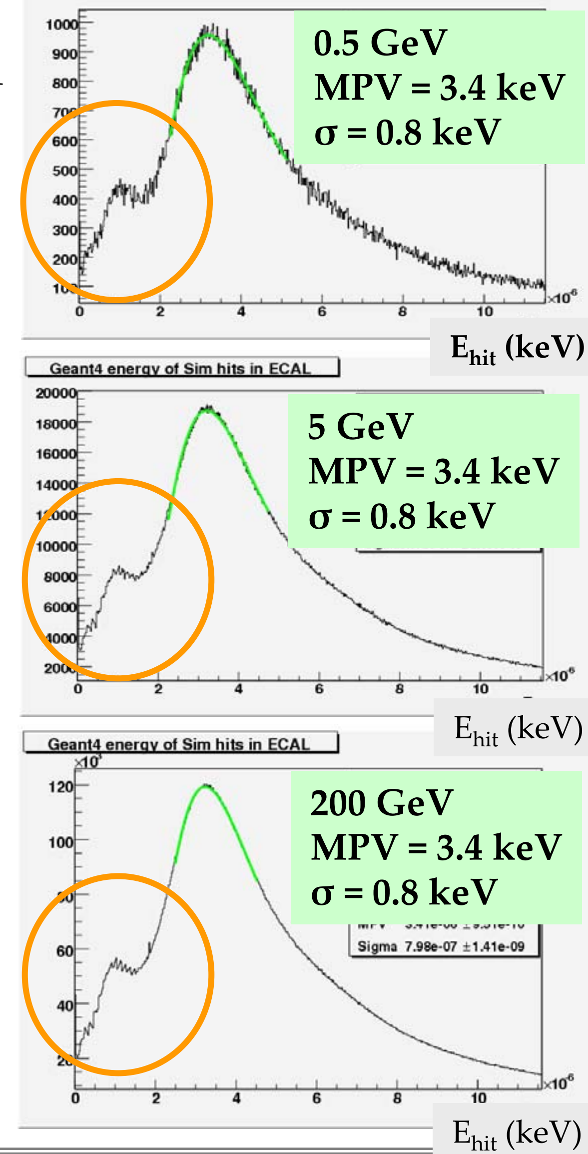
- MAPS Simulation implemented in MOKKA, with LDC01 for now on.
- MIP landau MPV stable vs energy @ Geant4 level
  ➔ Assumption of 1 MIP per cell checked up to 200 GeV,
- Definition of energy : $E\ \alpha\ N_{MIPS}$.
- Binary readout : need to find the optimal threshold, taking into account a 10^{-6} probability for the noise to fluctuate above threshold.

•**MIP crossing boundaries** : effect can be reduced by clustering

•So energy resolution is given by the distribution of hits/clusters above threshold:

$$\frac{\sigma_E}{E} \propto \frac{\sqrt{\sigma_{N_{pixels}}^{\ 2} + N_{noise}}}{N_{pixels}}$$

Geant4 energy of simulated hits



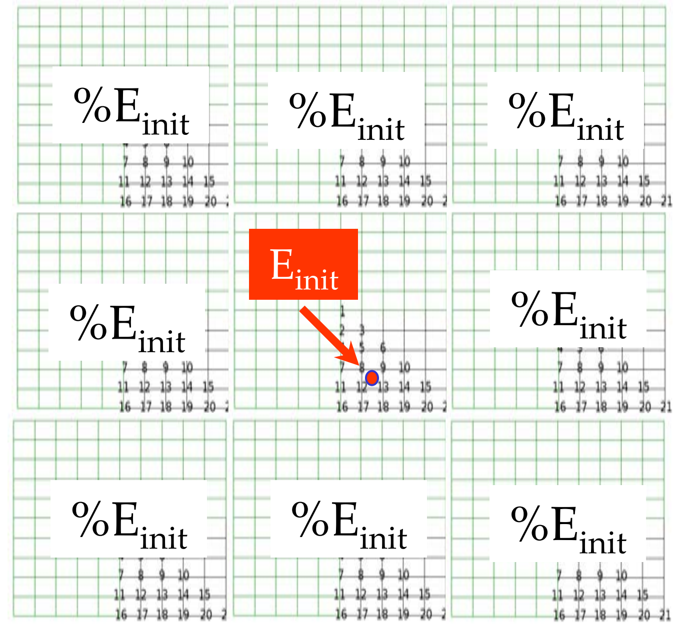
Digitisation procedure

Geant4 E_{init}
in 5x5 μm² cells

Apply charge spread
$E_{after\ charge\ spread}$

Register the position and the number of hits above threshold

+ noise only hits :
proba 10^{-6} ➔ ~ 10^{6} hits in the whole detector
BUT in
a 1.5*1.5 cm² tower : ~3 hits.



Importance of the charge spread :

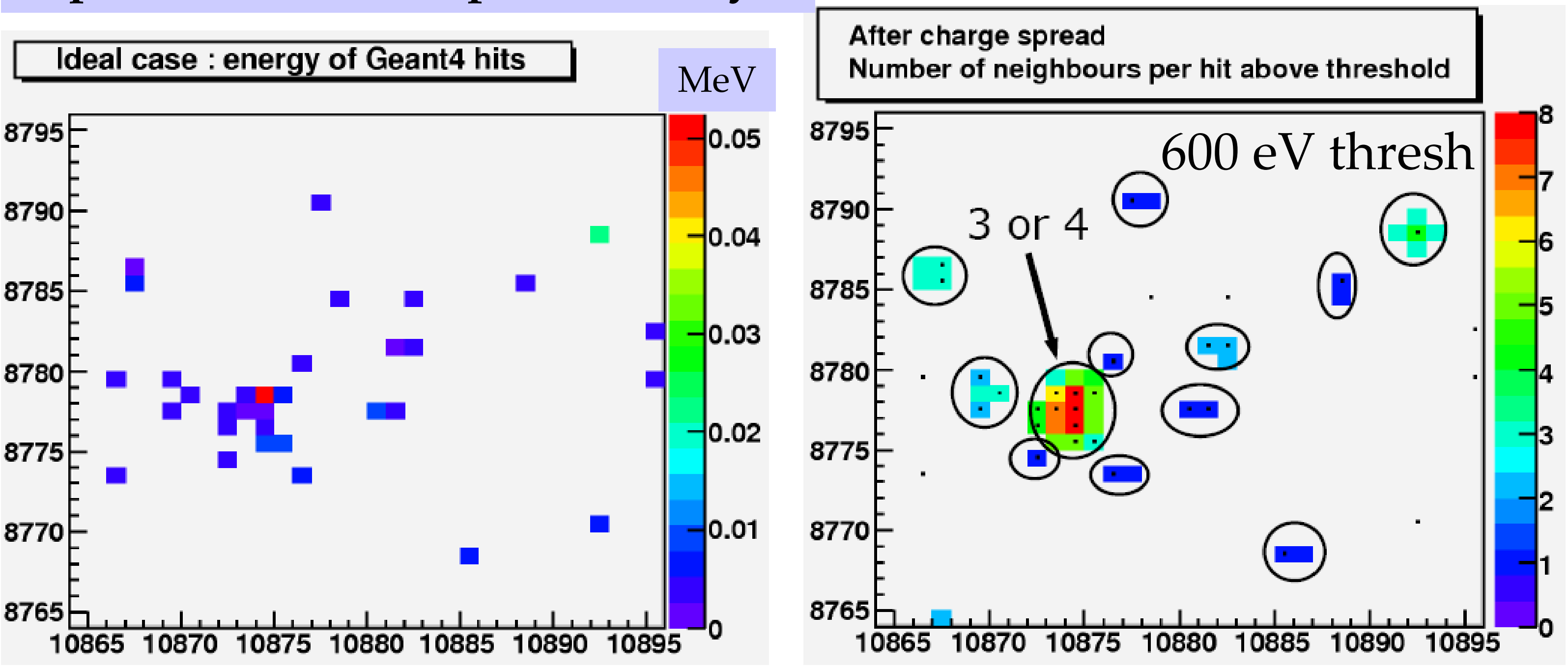
$$\sum E_{neighbours} \sim (50\% - 80\%) \times E_{init}$$

Sum energy in
50x50 μm² cells
E_{sum}

Add noise to signal hits
with σ = 100 eV
(1 e- ~ 3 eV ➔ 30 e- noise)

Simple clustering

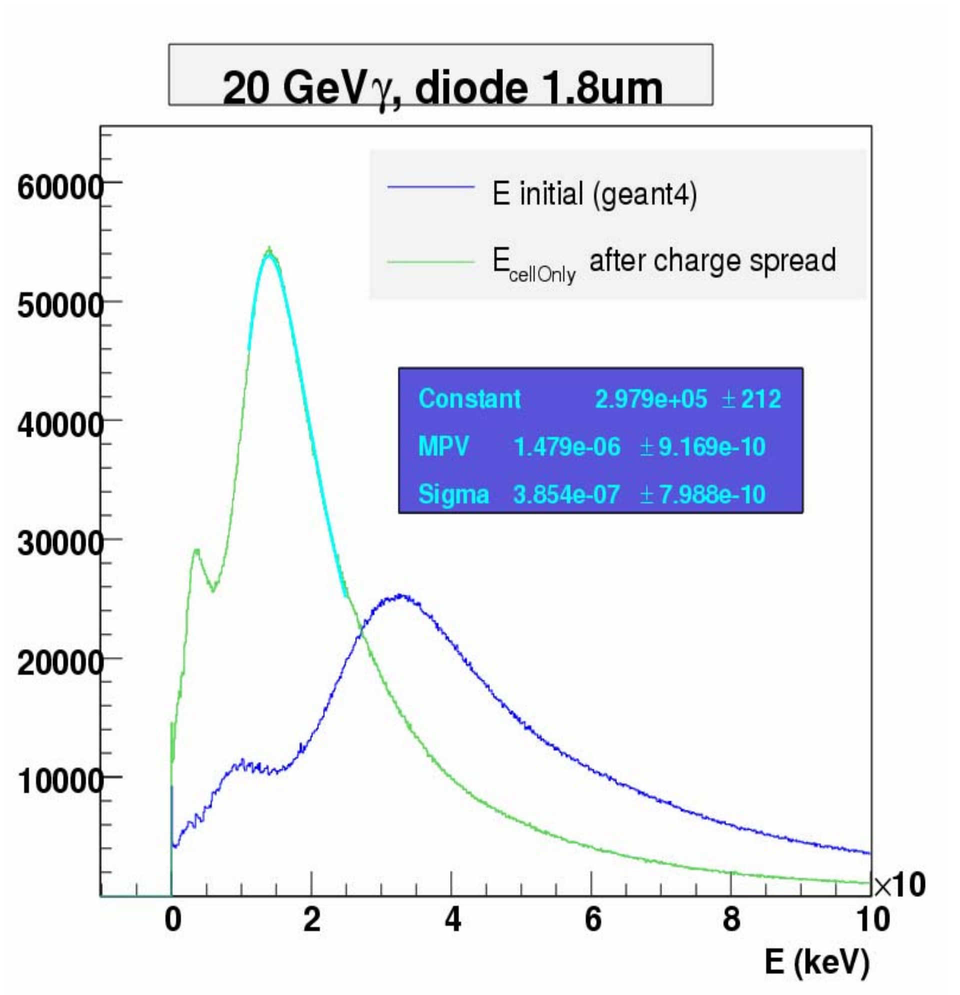
A particular event, a particular layer



- Loop over hits classified by number of neighbours :
- if < 8 : count 1 (or 2 for last 10 layers) and discard neighbours,
- if 8 and one of the neighbours has also 8 : count 2 (or 4) and discard neighbours.
- Not very optimised : lots of room for improvement !

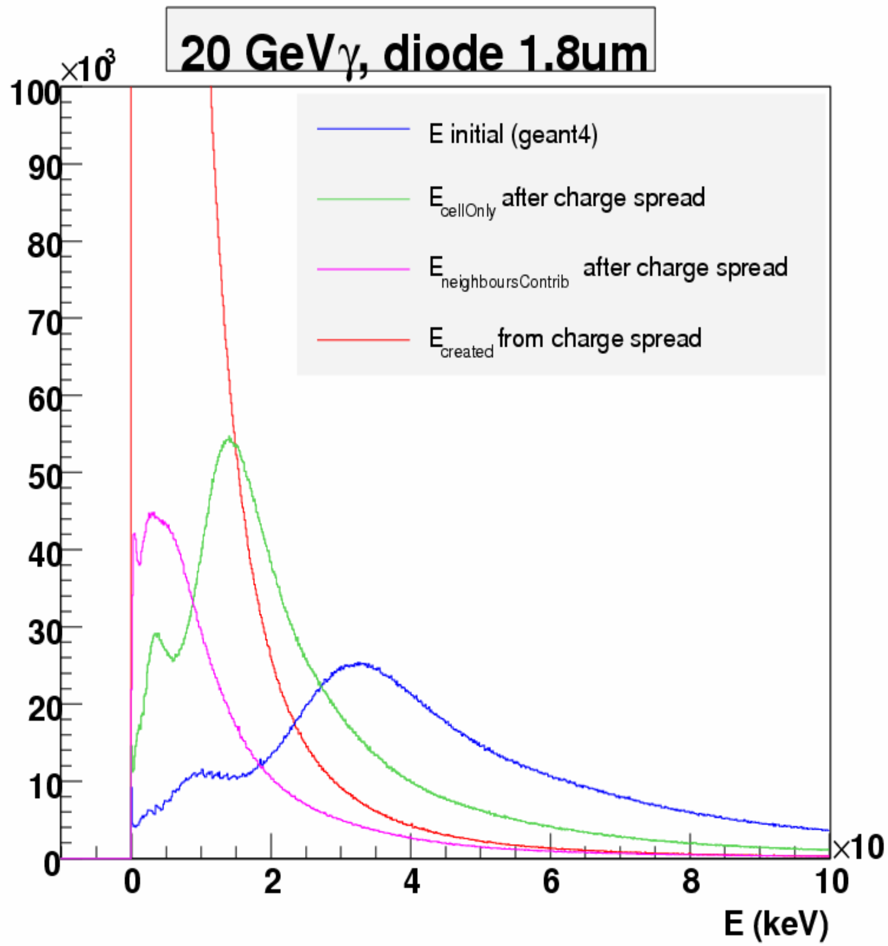
How is the energy affected by each digitisation step ?

- E initial : geant4 deposit
- What remains in the cell after charge spread assuming perfect P-well



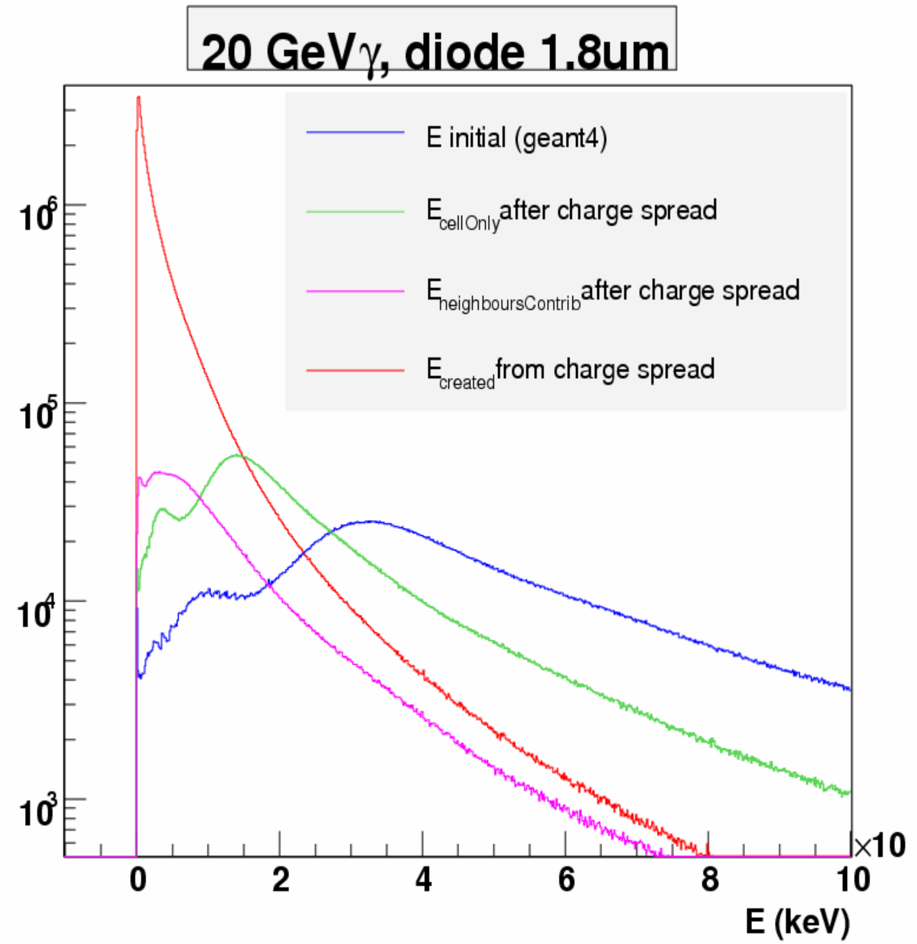
How is the energy affected by each digitisation step ?

- E initial : geant4 deposit
- What remains in the cell after charge spread assuming perfect P-well
- Neighbouring hit:
  - hit ? Neighbour's contribution
  - no hit ? Creation of hit from charge spread only



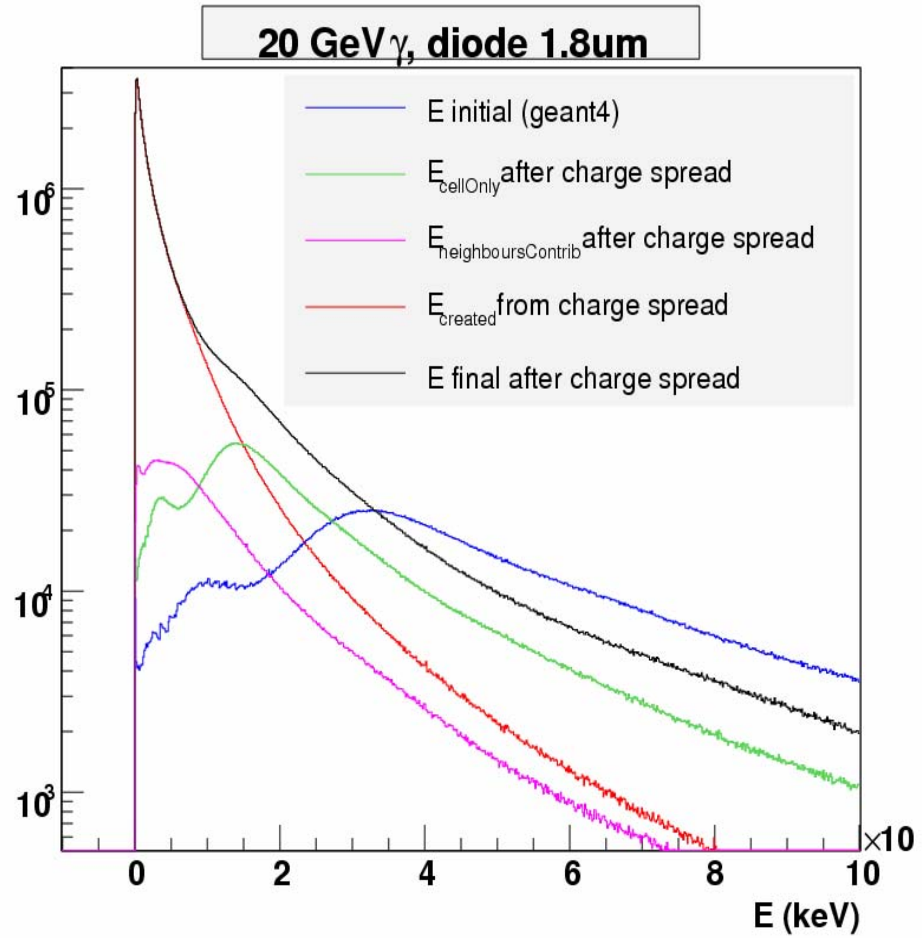
How is the energy affected by each digitisation step ?

- E initial : geant4 deposit
- What remains in the cell after charge spread assuming perfect P-well
- Neighbouring hit:
  - hit ? Neighbour's contribution
  - no hit ? Creation of hit from charge spread only



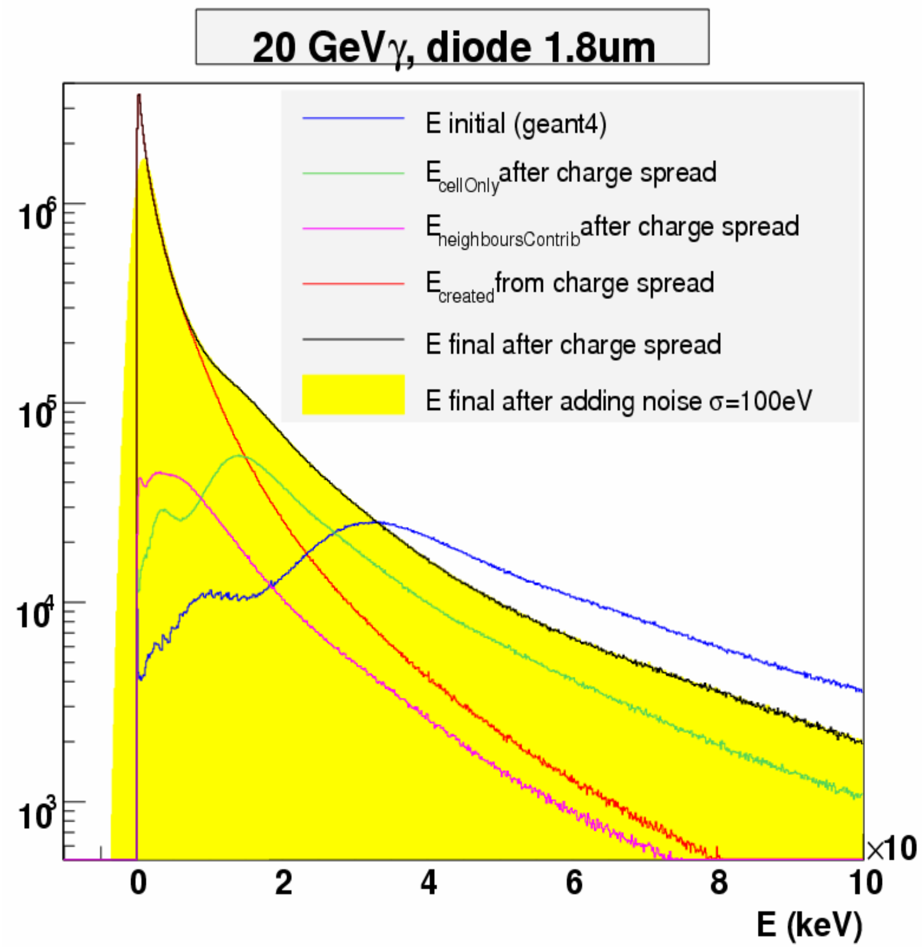
How is the energy affected by each digitisation step ?

- E initial : geant4 deposit
- What remains in the cell after charge spread assuming perfect P-well
- Neighbouring hit:
  - hit ? Neighbour's contribution
  - no hit ? Creation of hit from charge spread only
- All contributions added per pixel



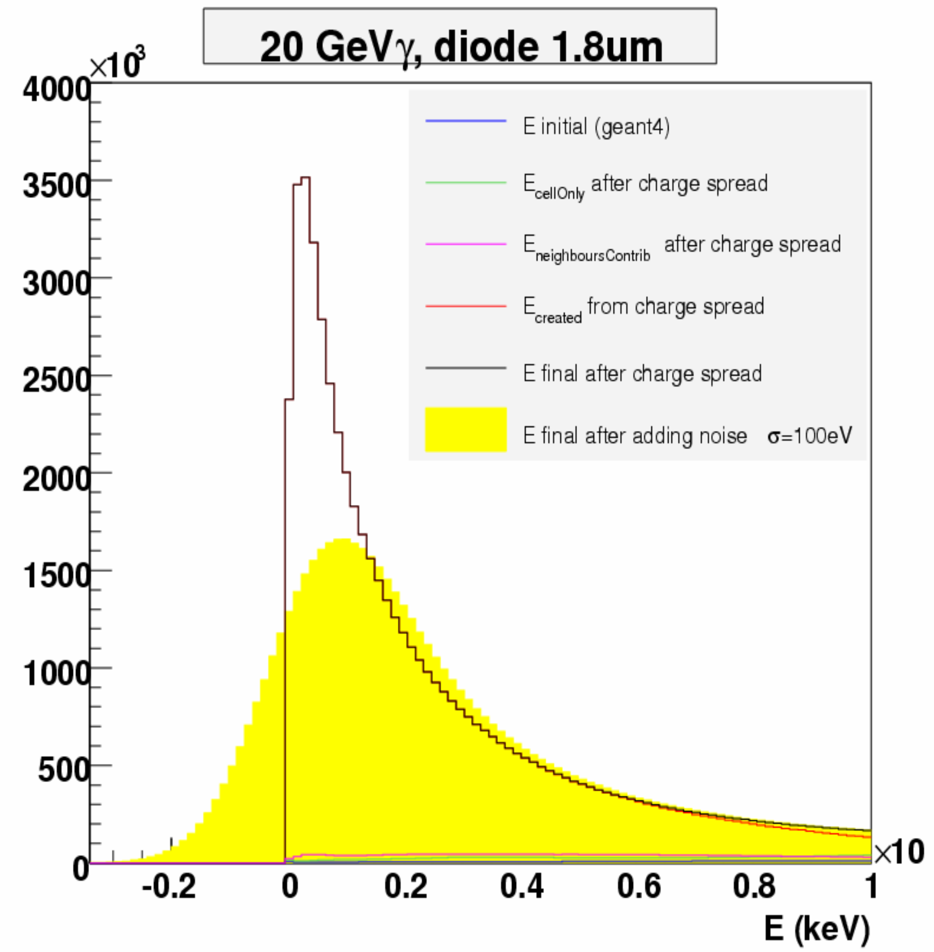
How is the energy affected by each digitisation step ?

- E initial : geant4 deposit
- What remains in the cell after charge spread assuming perfect P-well
- Neighbouring hit:
  - hit ? Neighbour's contribution
  - no hit ? Creation of hit from charge spread only
- All contributions added per pixel
- + noise σ = 100 eV



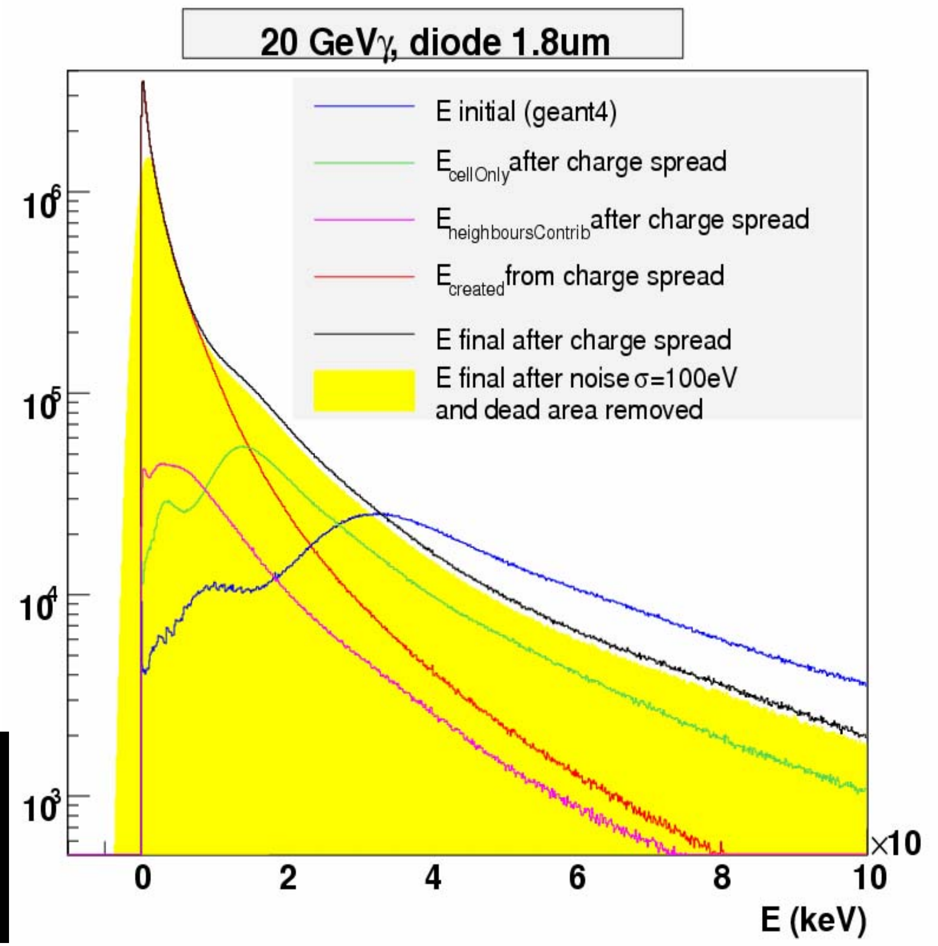
How is the energy affected by each digitisation step ?

- E initial : geant4 deposit
- What remains in the cell after charge spread assuming perfect P-well
- Neighbouring hit:
  - hit ? Neighbour's contribution
  - no hit ? Creation of hit from charge spread only
- All contributions added per pixel
- + noise σ = 100 eV



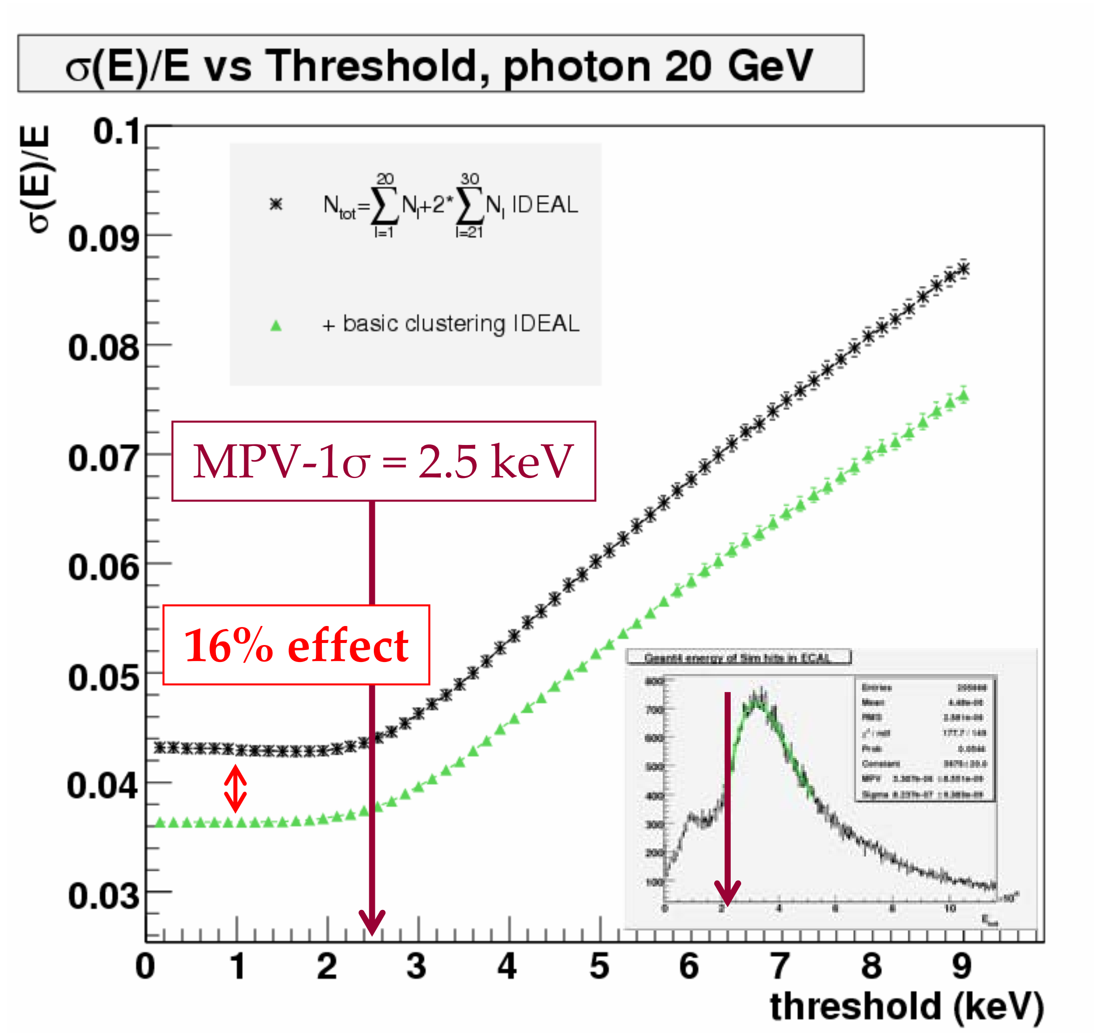
How is the energy affected by each digitisation step ?

- E initial : geant4 deposit
- What remains in the cell after charge spread assuming perfect P-well
- Neighbouring hit:
  - hit ? Neighbour's contribution
  - no hit ? Creation of hit from charge spread only
- All contributions added per pixel
- + noise σ = 100 eV
- + noise σ = 100 eV, minus dead areas : 5 pixels every 42 pixels in one direction



Effect of the clustering on the energy resolution

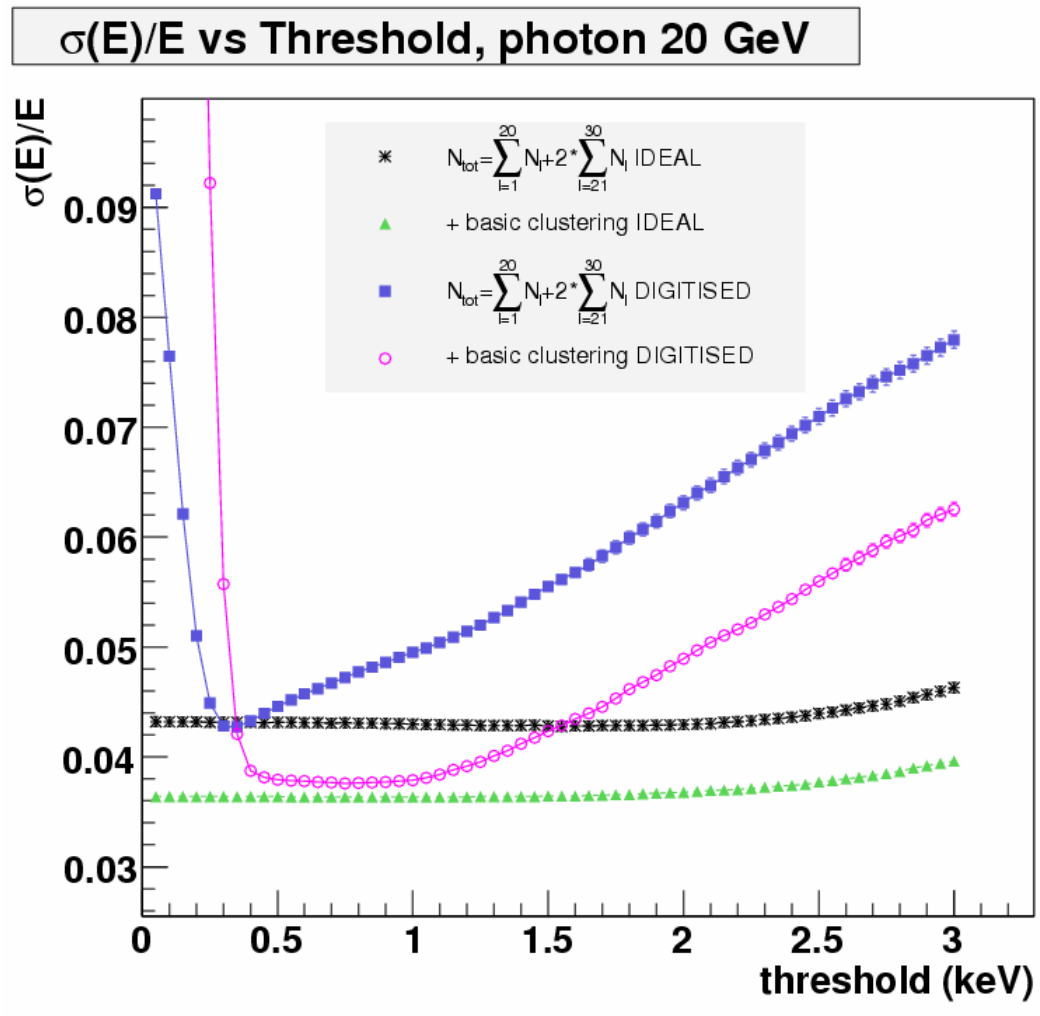
IDEAL : Geant4 energy,
- ✓ no charge spread,
- ✓ no noise,
- ✓ dead area removed (5 pixels every 42 pixels in one direction)
- ✓ without or with clustering



Effect of the clustering on the energy resolution

IDEAL : Geant4 energy,
✓ no charge spread,
✓ no noise,
✓ dead area removed (5 pixels every 42 pixels in one direction)
✓ without or with clustering

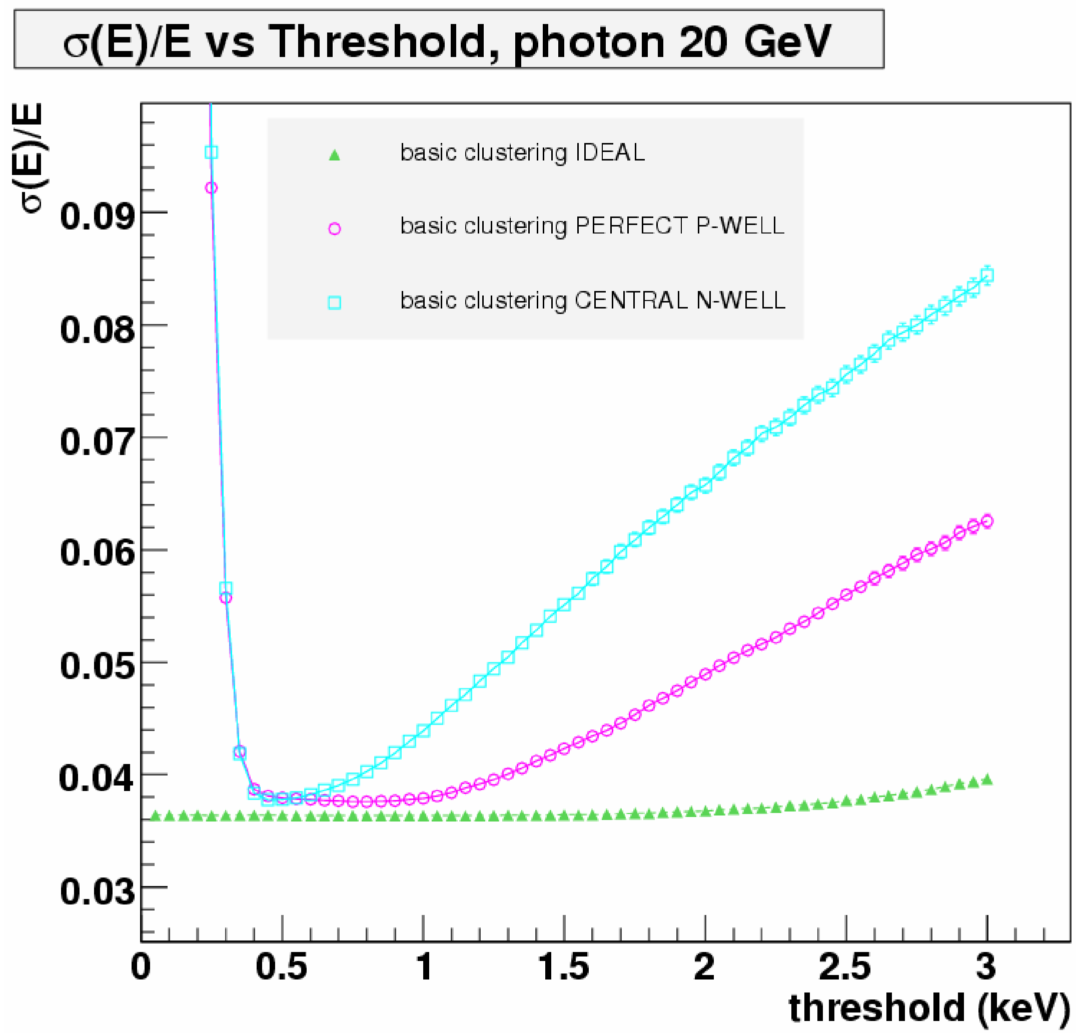
DIGITIZED:
✓ charge spread with perfect P-well assumed,
✓ noise σ=100 eV,
✓ 10^{-5} probability of a pixel to be above threshold
✓ dead area removed
✓ without or with clustering



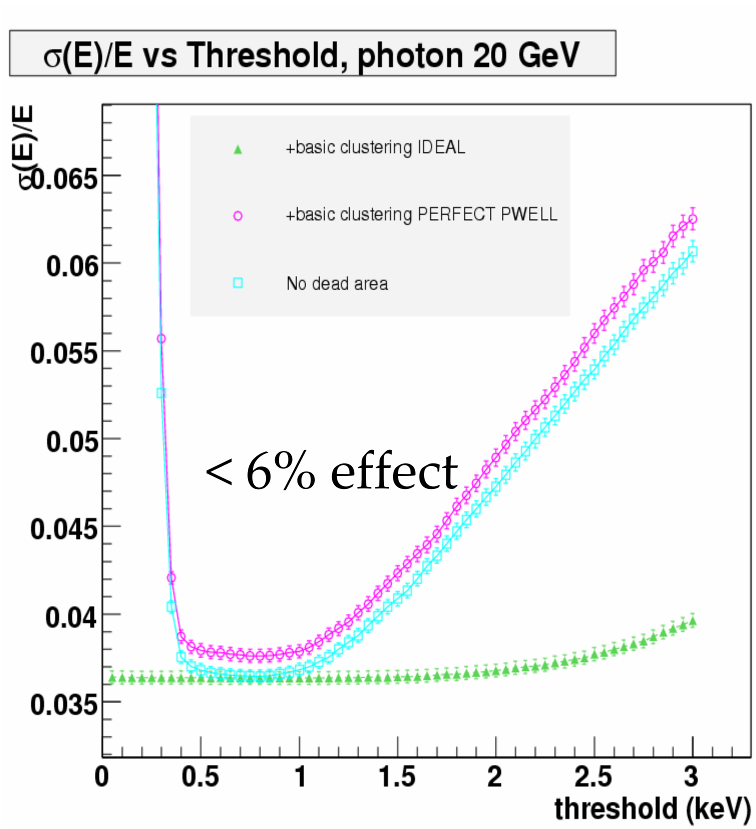
Effect of charge spread model

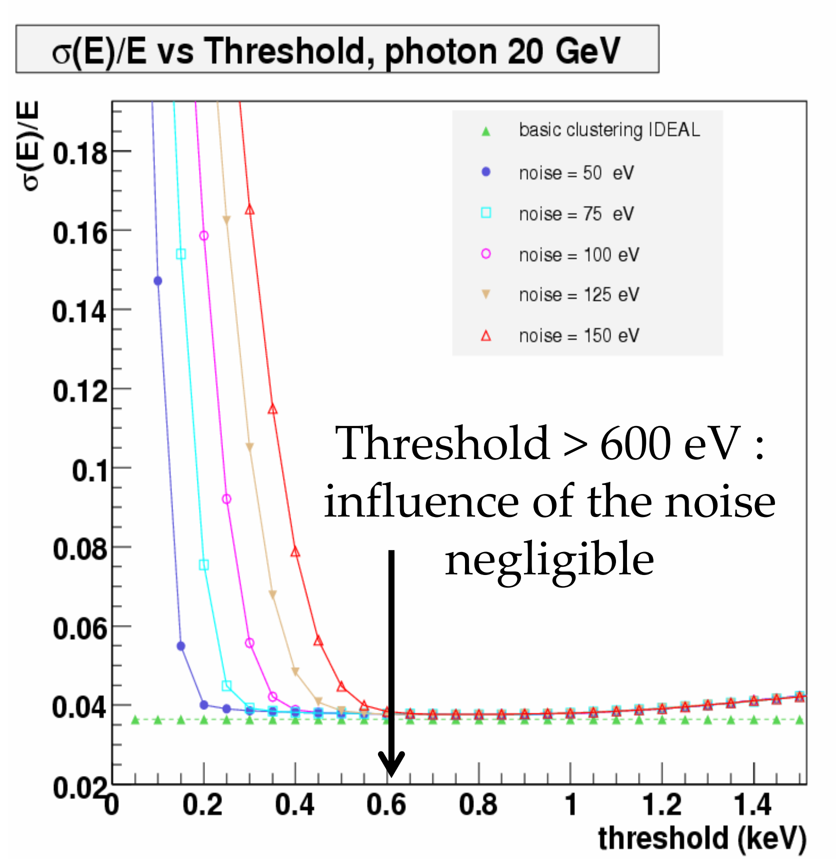
Optimistic scenario:
Perfect P-well after clustering: large minimum plateau ➔ large choice for the threshold !!

Pessimistic scenario:
Central N-well absorbs half of the charge, but minimum is still in the region where noise only hits are negligible + same resolution !!!



Effect of dead area and noise after clustering

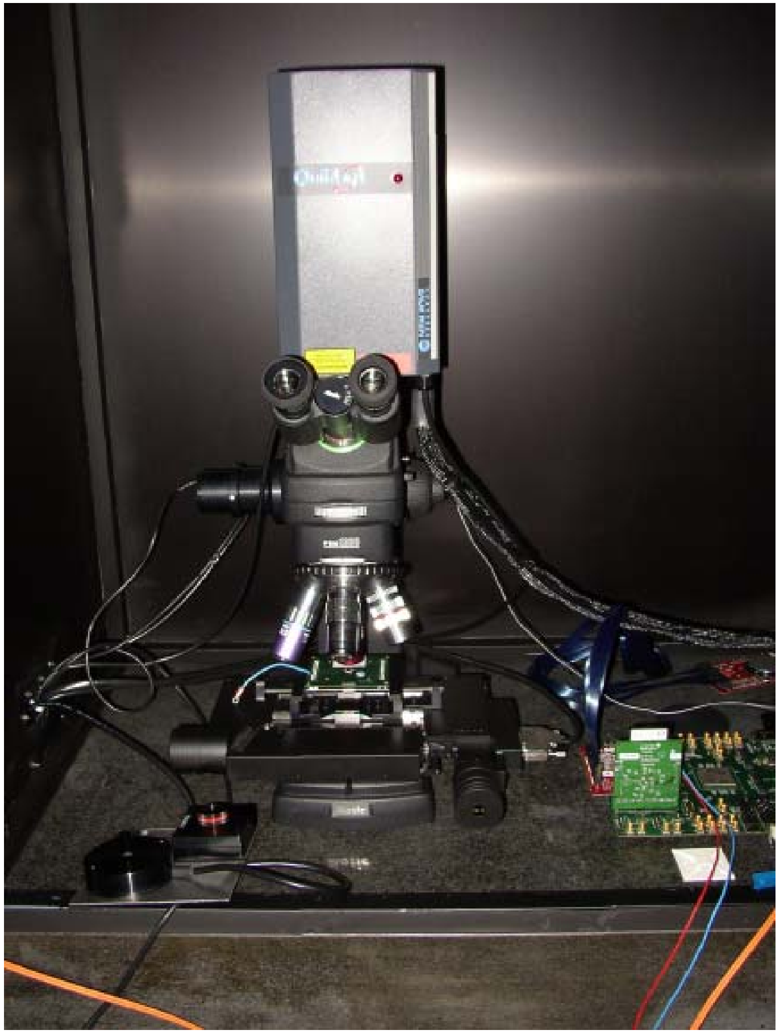




➔energy resolution dependant on a lot of parameters : need to measure the noise and the charge spread ! And improve the clustering, especially at high energy.

Plans for the summer

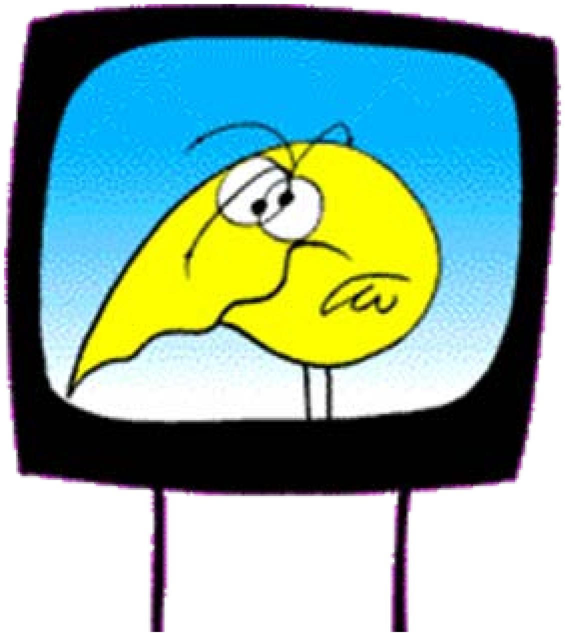
- Sensor has been submitted to foundry on April 23rd, back in July.
- Charge diffusion studies with a powerful laser setup at RAL :
  - 1064, 532 and 355 nm wavelength,
  - focusing < 2 μm,
  - pulse 4ns, 50 Hz repetition rate,
  - fully automatized
- Cosmics and source setup to provide by Birmingham and Imperial respectively.
- Work ongoing on the set of PCBs holding, controlling and reading the sensor.
- possible beam test at DESY at the end of this year.



Conclusion

- Sensor v1.0 has been submitted. We aim to have first results in the coming months!
- Test are mandatory to measure the sensor charge spread and noise for digitisation simulation.
- Once we trust our simulation, detailed physics simulation of benchmark processes and comparison with analog ECAL design will be possible.

CALICE
Calorimeter for LC

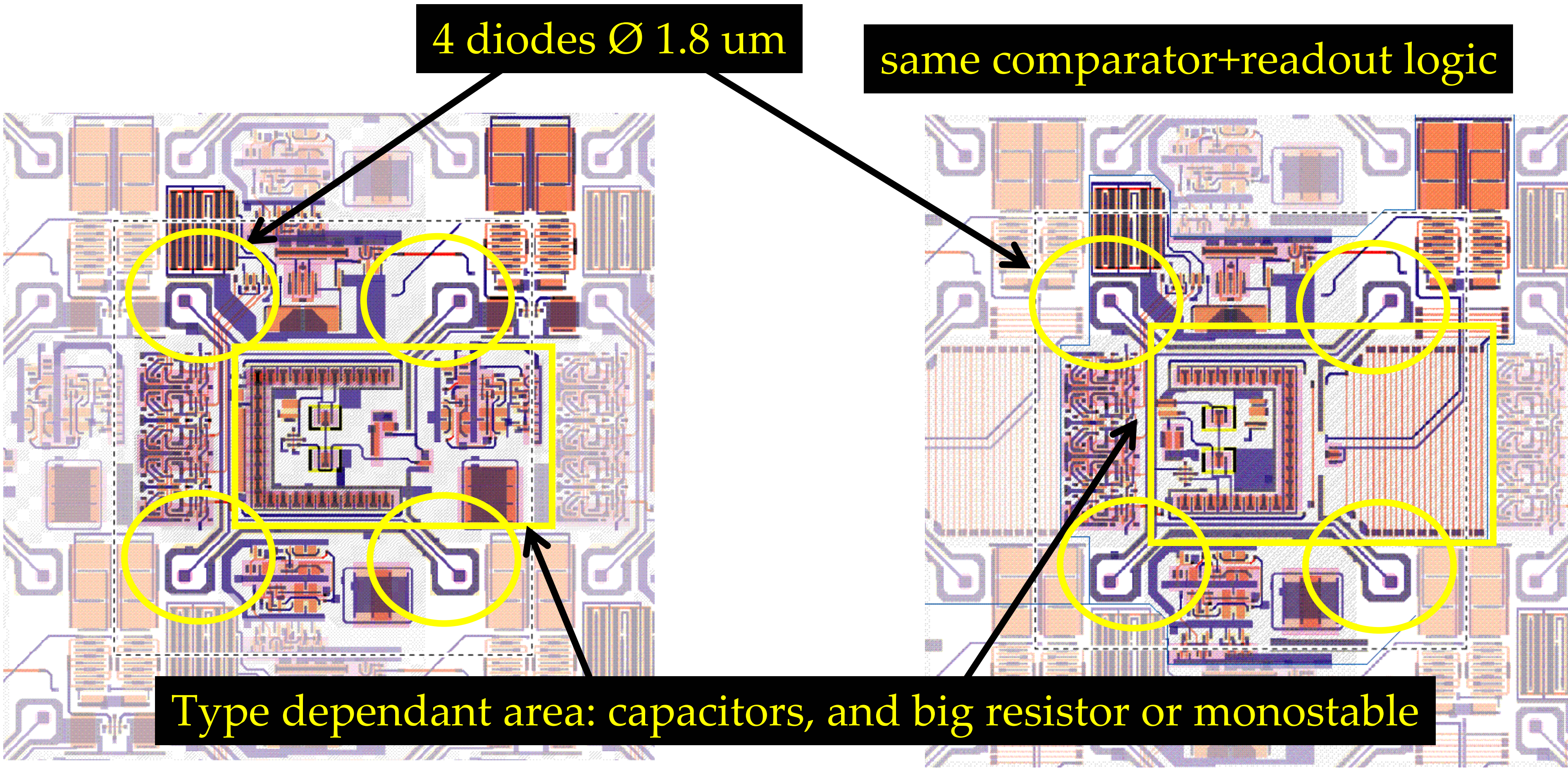


Thank you for your attention

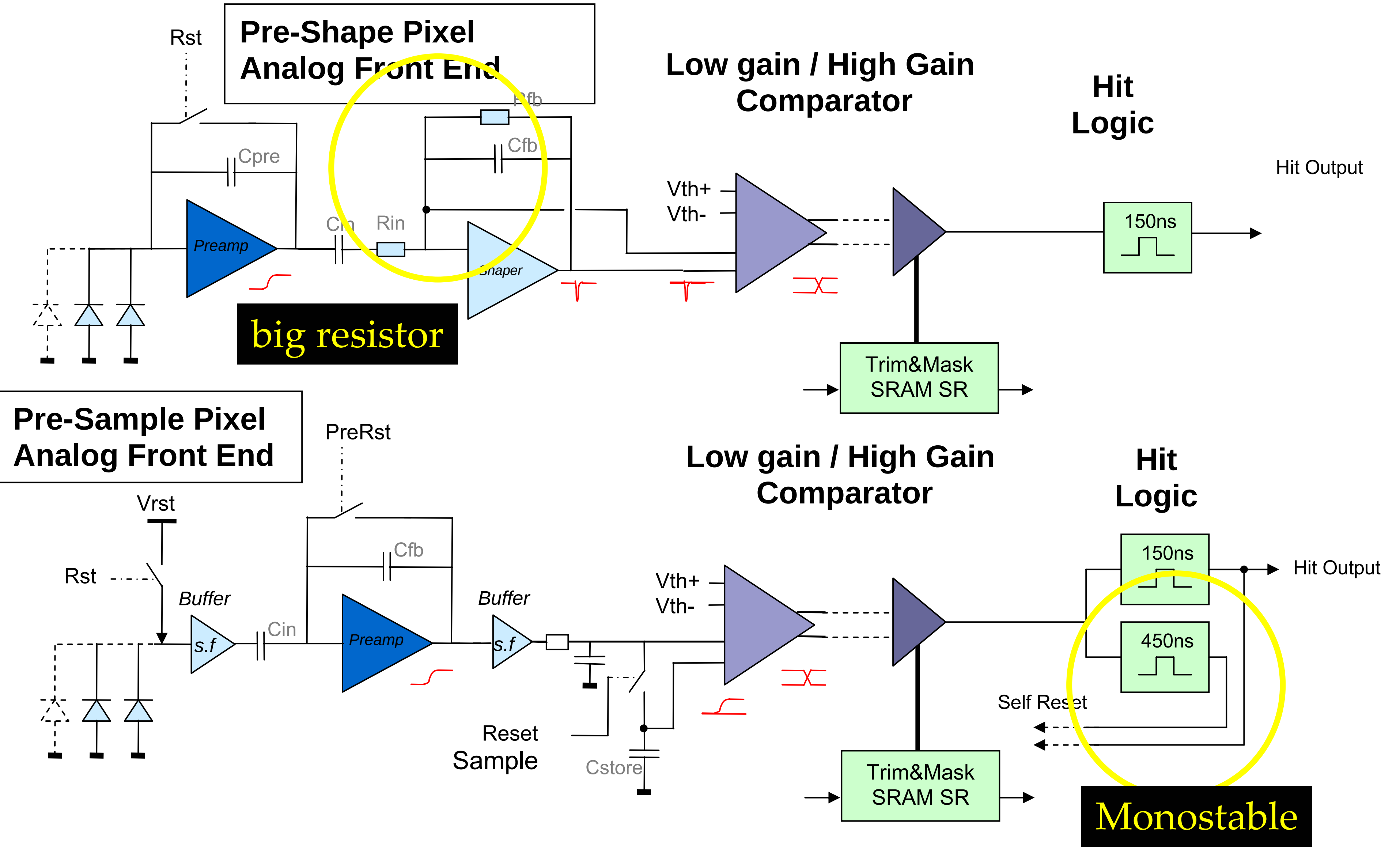
Sensor layout : v1.0 submitted !

<u>Design submitted April 23rd :</u>

Presampler | Preshaper

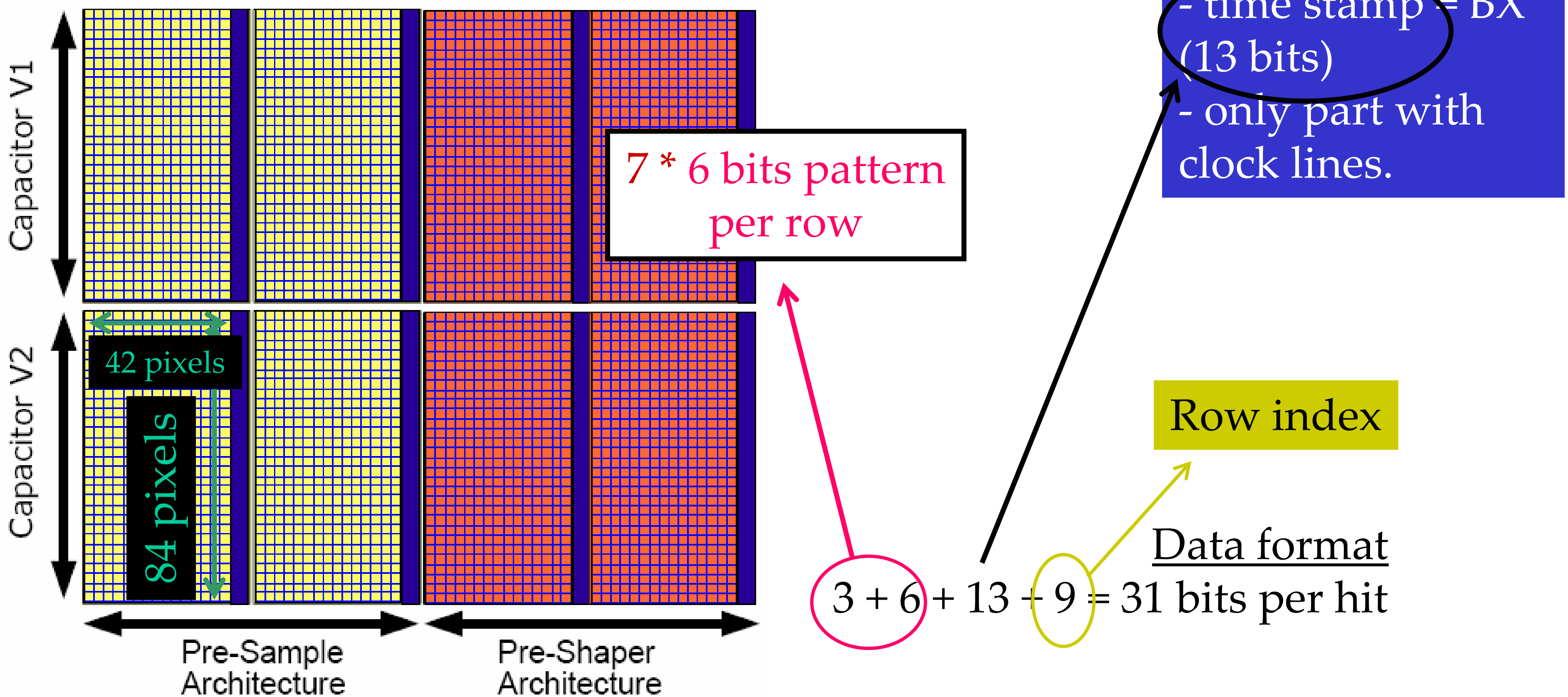


THE DesignS


Pre-Shape Pixel
Analog Front End
Rst
Cpre
Preamp
Cin
Rin
Rfb
Cfb
Shaper
big resistor
Low gain / High Gain
Comparator
Vth+
Vth-
Hit
Logic
Hit Output
150ns
Trim&Mask
SRAM SR
Pre-Sample Pixel
Analog Front End
PreRst
Vrst
Rst
Buffer
s.f
Cin
Cfb
Preamp
Buffer
s.f
Reset
Sample
Cstore
Low gain / High Gain
Comparator
Vth+
Vth-
Hit
Logic
150ns
450ns
Hit Output
Self Reset
Trim&Mask
SRAM SR
Monostable

The sensor test setup

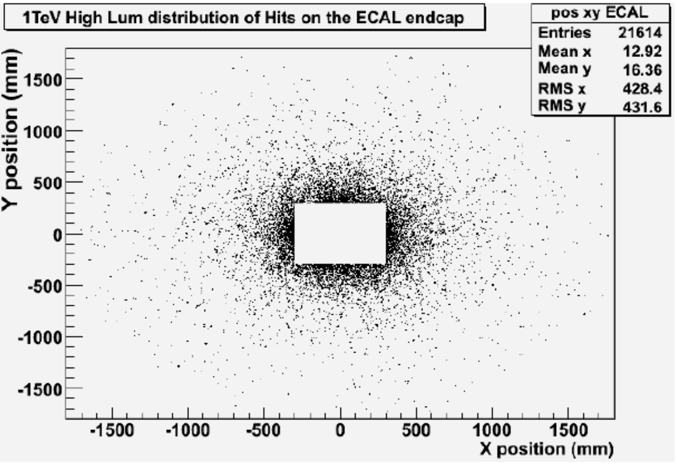
1*1 cm² in total
2 capacitor arrangements
2 architectures
6 million transistors, 28224 pixels

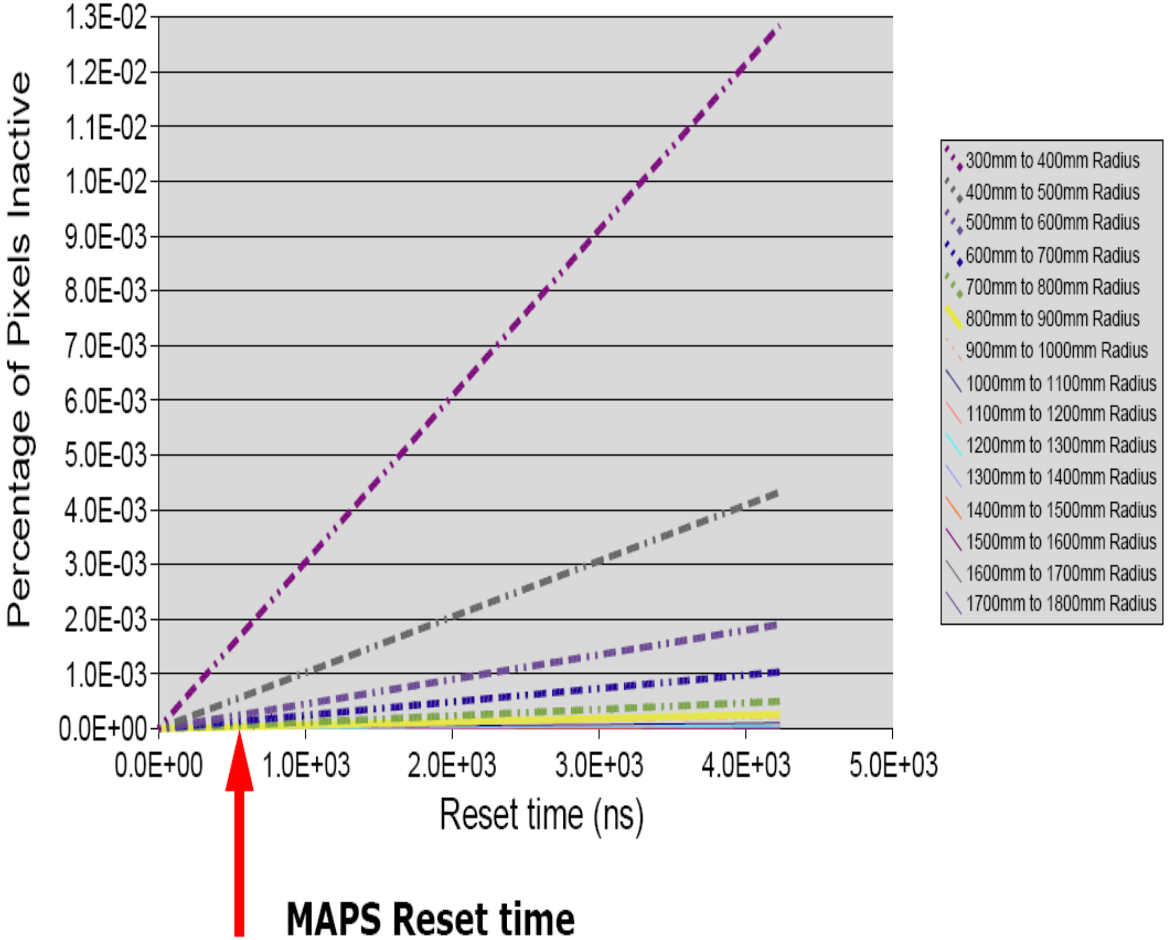


Beam background studies

- Done using GuineaPig
- 2 scenarios studied :
  - 500 GeV baseline,
  - 1 TeV high luminosity.

purple = innermost endcap radius
500 ns reset time ➔ ~ 2‰ inactive pixels





Particle Flow: work started !

- Implementing PandoraPFA from Mark Thomson : now running on MAPS simulated files.
- **First plots** with Z->uds @ 91 GeV in ECAL barrel gives a resolution of 35% / √E before digitisation and clustering