Progress Report on the MAPS ECAL R&D

on behalf of the MAPS group:

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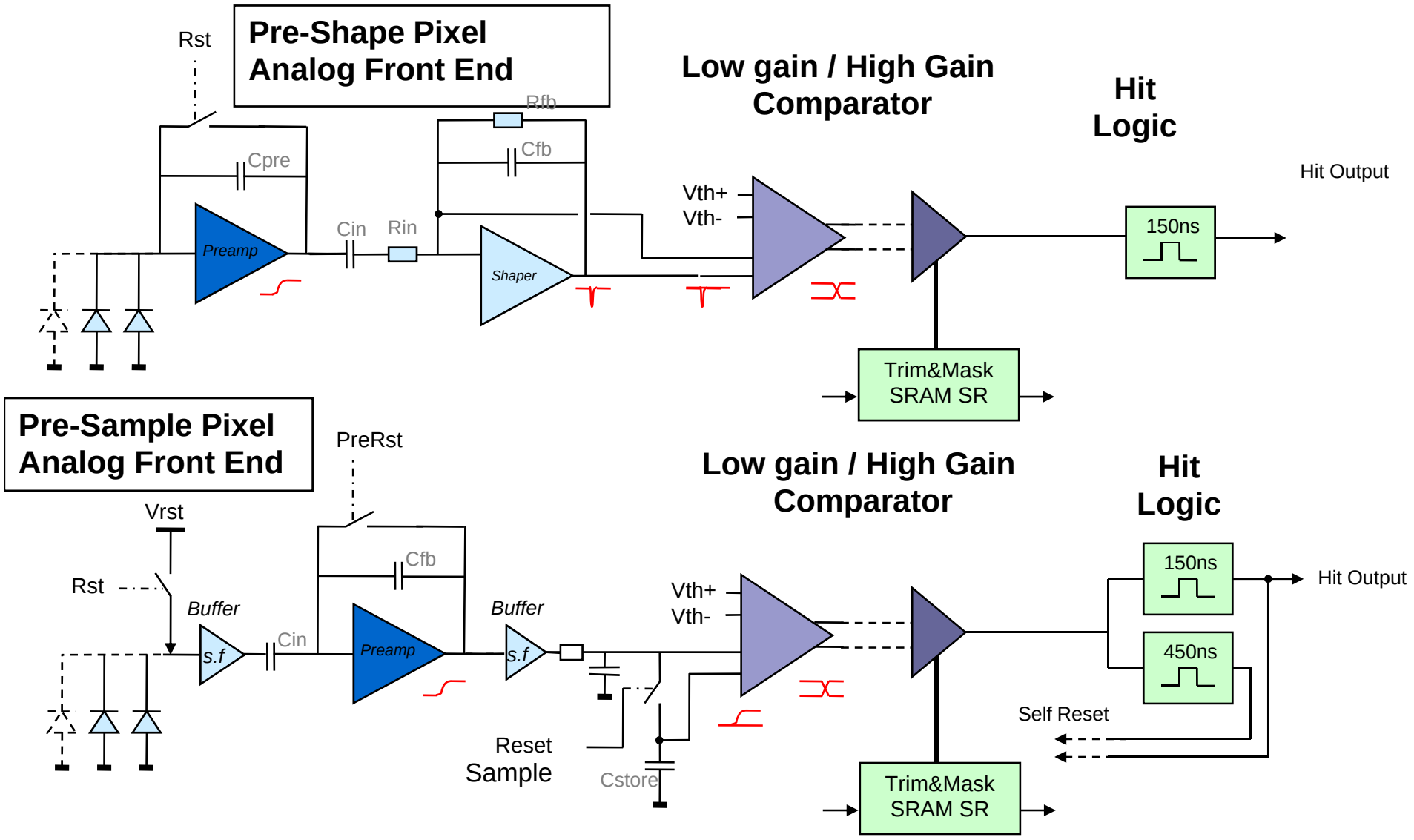
Quick Reminder on MAPS

- Monolithic Active Pixel Sensor : based on CMOS technology, in-pixel comparator and logic.
- Really small for an ECAL, large for a standard MAPS : 50*50 μm^2 pixels.
- 10^{12} pixels = digital readout.
- Noise objective : probability of 10^{-6} hits above threshold = DAQ has to handle ~10^6 hits per event! Output will be a simple list of geometrical indices of hits above threshold.
- First design of sensors submitted to foundry 2 weeks ago !! Will be back in July.

Outline

- Overview of the designs submitted and how the pixels work
- Sensor simulations : how the charge is collected
- Geant4 simulation and digitisation : how to go from the ideal Geant4 energy deposit to a realistic digital output
- Plans for this summer
- Conclusion and longer term plans

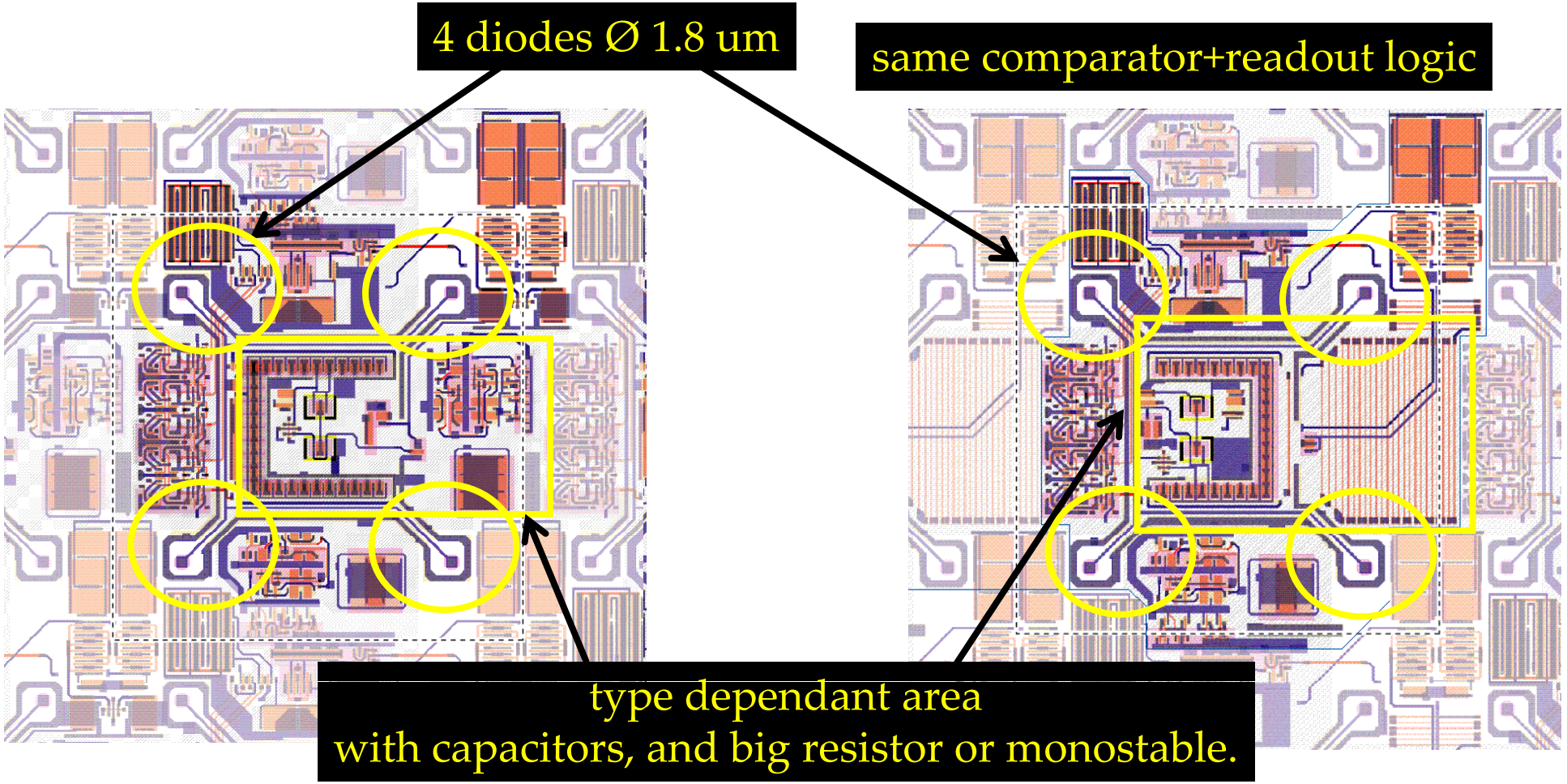
THE DesignS


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

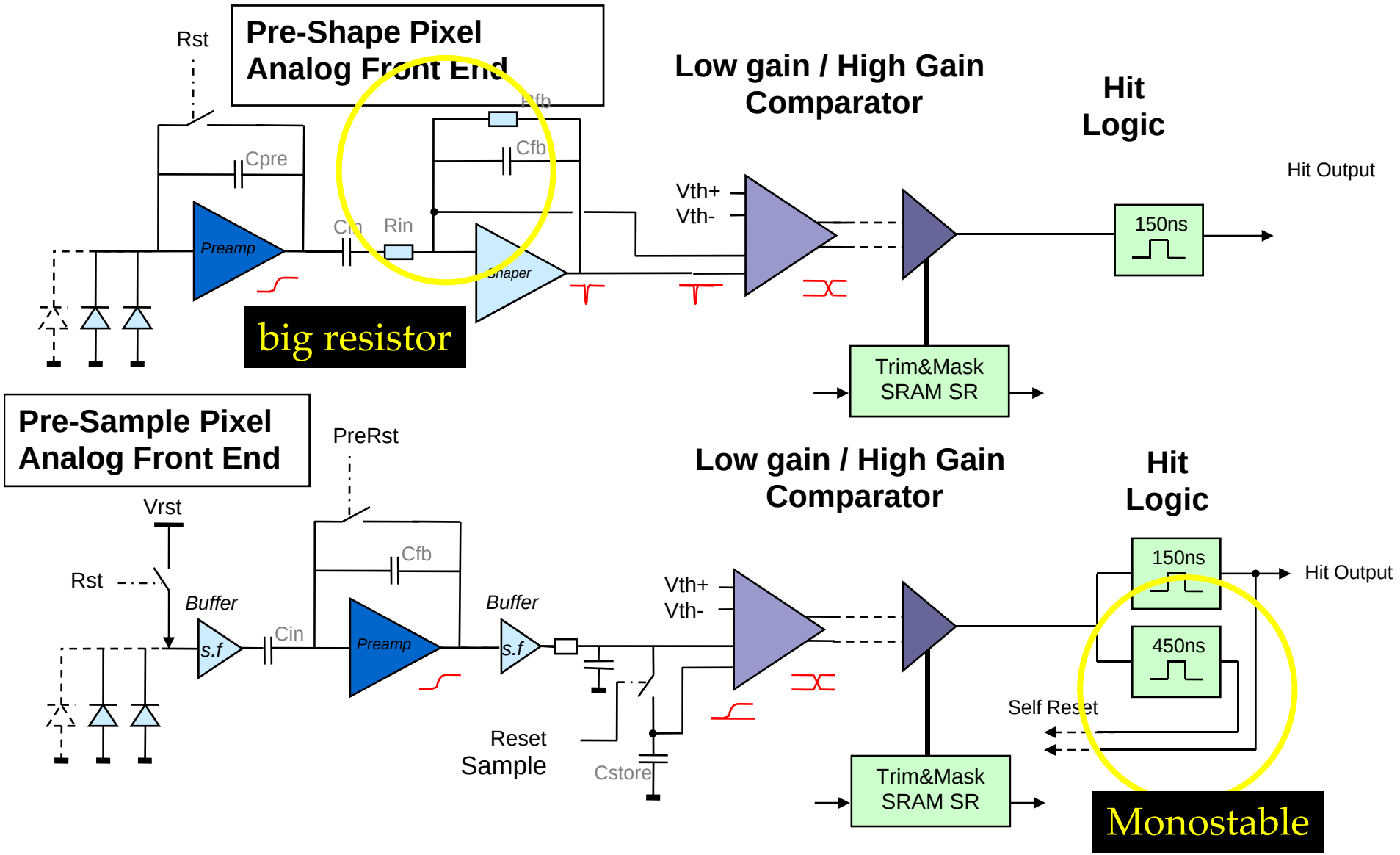
and pretty pictures…

Presampler

Preshaper



THE DesignS

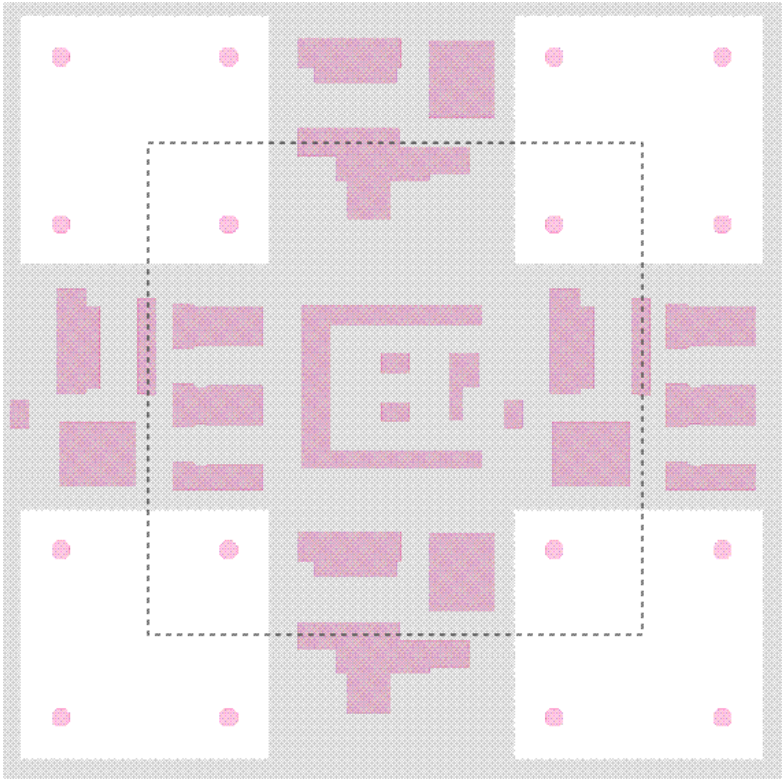

Pre-Shape Pixel
Analog Front End
Rst
Cpre
Preamp
Cin
Rin
Cfb
Shaper
big resistor
Low gain / High Gain
Comparator
Vth+
Vth-
Hit
Logic
Hit Output
150ns
Trim&Mask
SRAM SR
Pre-Sample Pixel
Analog Front End
PreRst
Vrst
Rst
Buffer
s.f
Cin
Cfb
Preamp
Buffer
s.f
Reset
Sample
Cstore
Low gain / High Gain
Comparator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

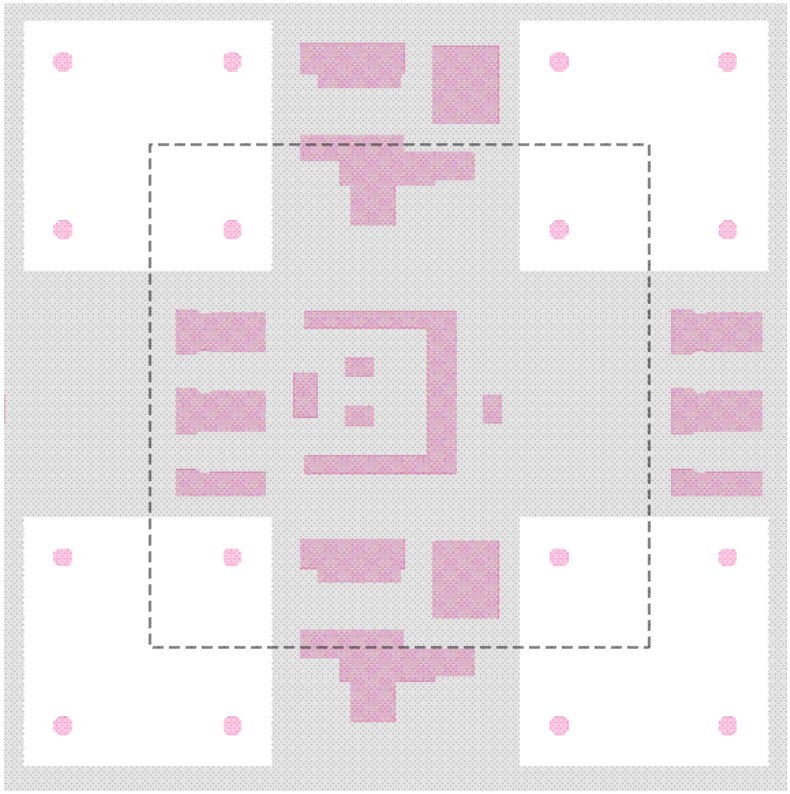
What's eating charges : the N-well distribution in the pixels

Presampler

Preshaper

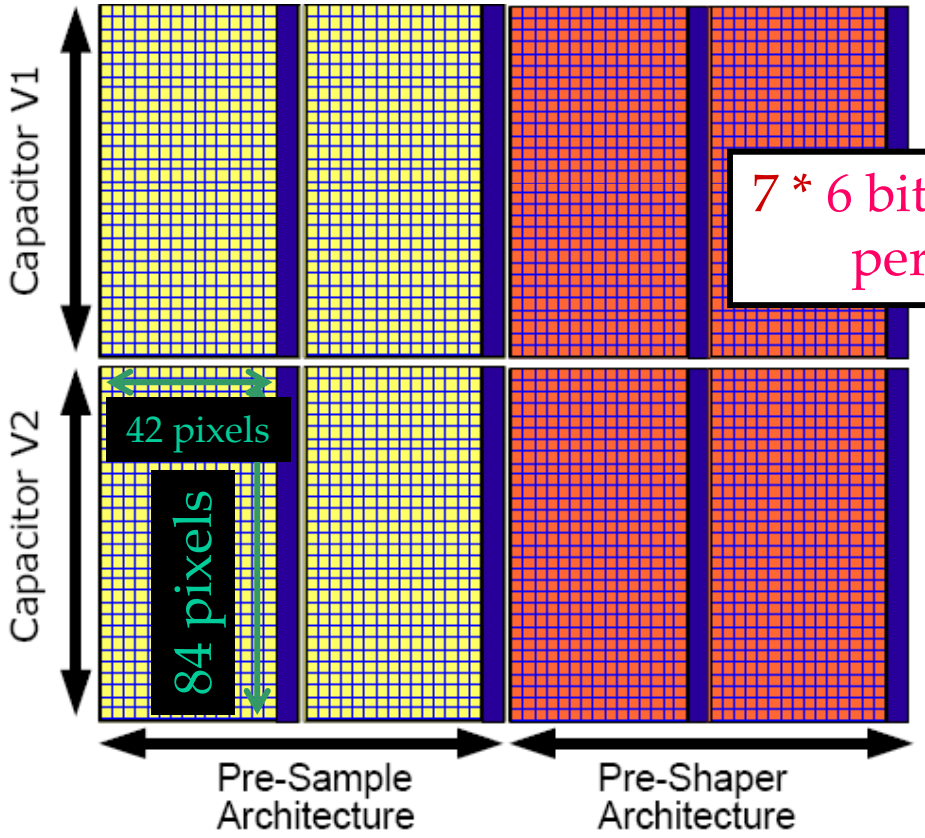
purple = nwell (eating charge)
blue = deep p-well added to block the charge absorption
INMAPS process





The sensor test setup

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



7 * 6 bits pattern per row

5 dead pixels for logic :
-hits buffering (SRAM)
- time stamp = BX (13 bits)
- only part with clock lines.

Row index

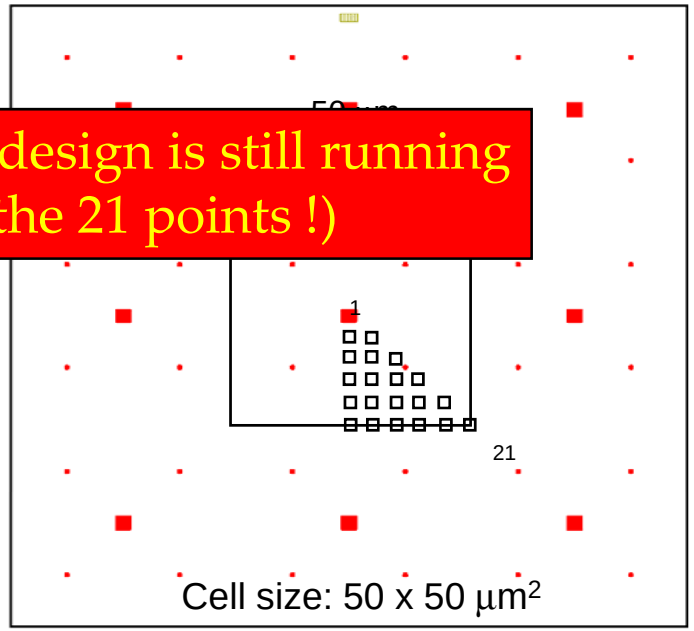
Data format

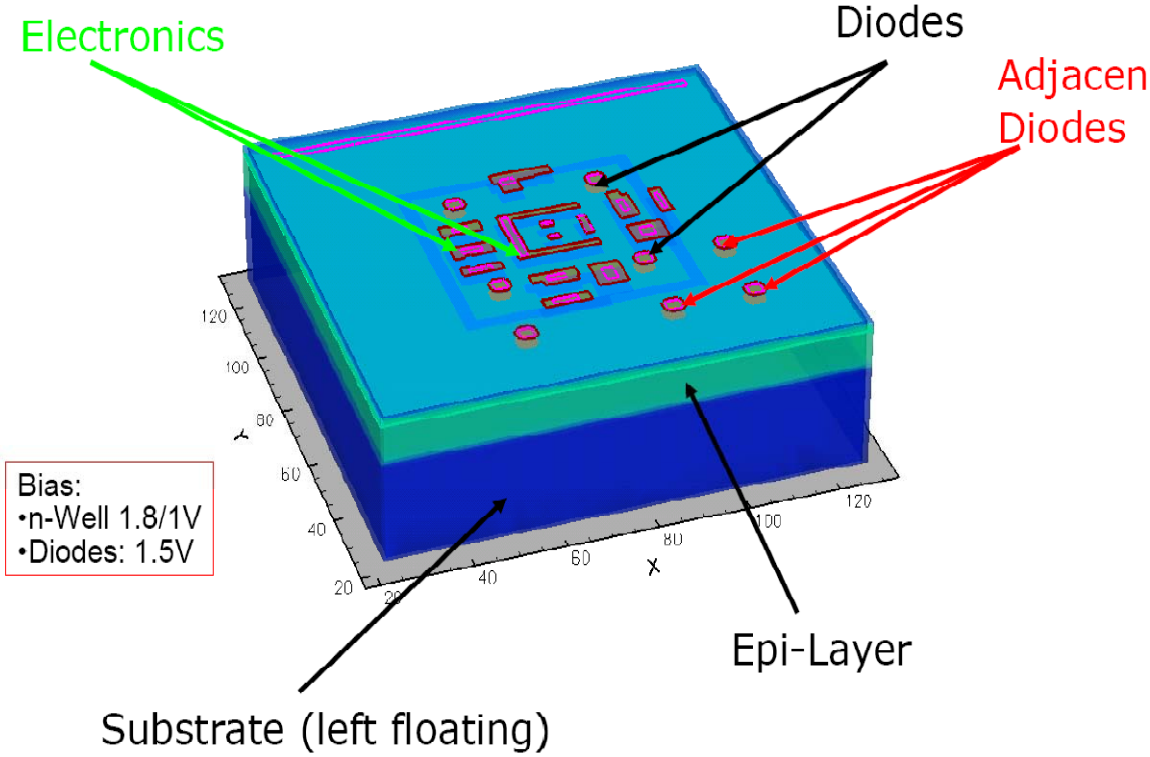
3 + 6 + 13 + 9 = 31 bits per hit

The sensor simulation setup

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

Simulation for the final design is still running (~3 weeks to do the 21 points !)



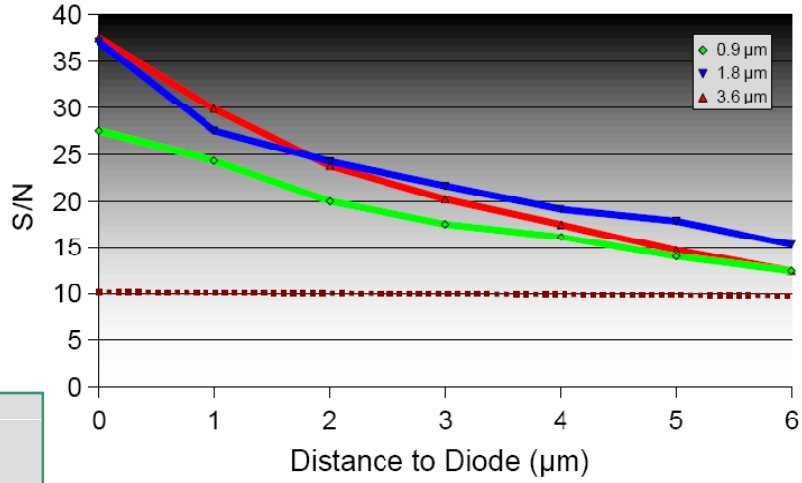


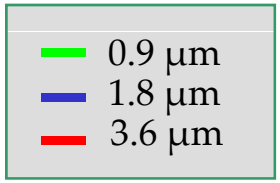
Whole 3*3 array with neighbouring cells is simulated, and the initial charge is inputed on 21 points (sufficient to cover the whole pixel by symmetry)

Optimisation of some parameters

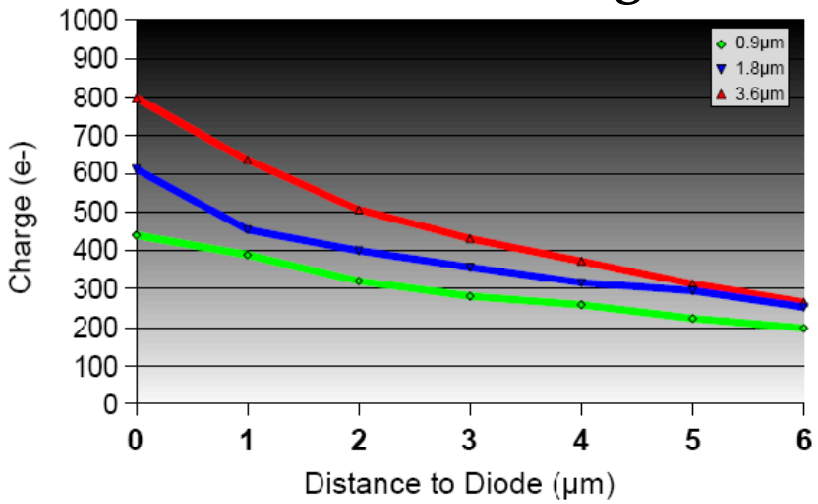
- Diode size has been optimised in term of signal over noise ratio, charge collected in the cell in the worse scenario (hit at the corner, point #21), and collection time.
- Diodes place is restricted by the pixels designs, e.g. to minimise capacitance effects

Signal over noise





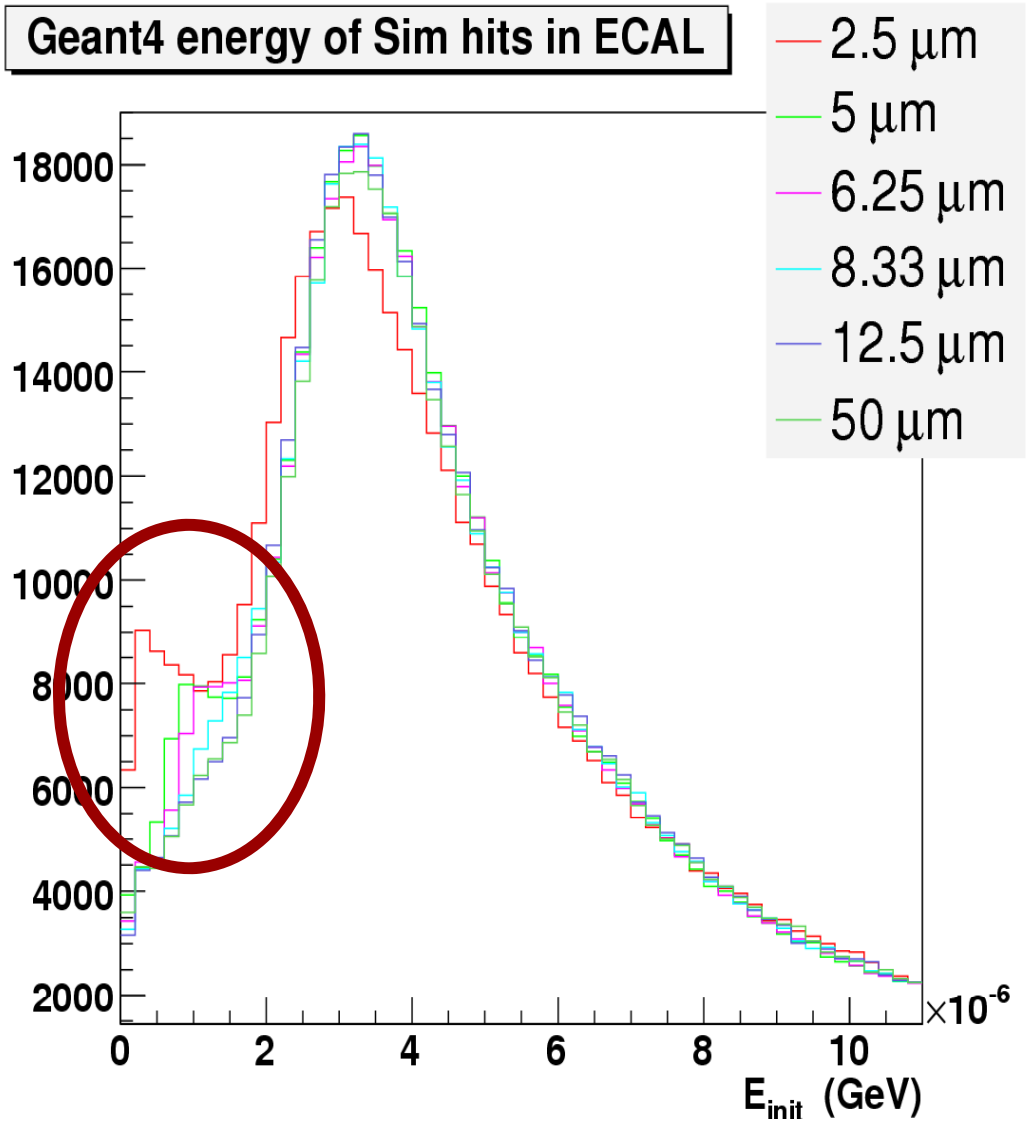
Collected charge



Geant4 simulation and digitisation

- Geant 4 simulation is currently done with MOKKA for LDC01 detector, with 15 µm epitaxial layer thickness.
- plans to use SLIC for SiD as well….
- One issue with small size is observed when adding up the energy to big size…

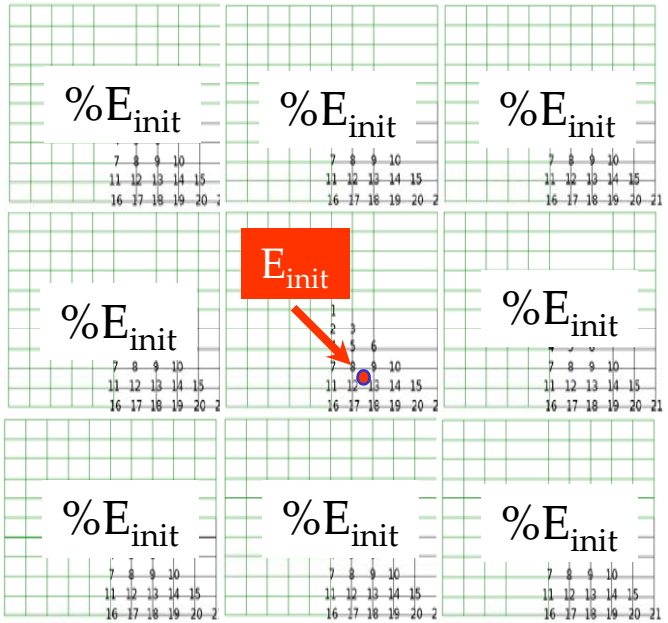
  ➔bug ????



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 (pessimistic scenario):
proba 10^{-5} ➔ ~ 10^7 hits in the whole detector
BUT in
a 1.5*1.5 cm² tower : ~30 hits.

Importance of the charge spread :

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

Add noise to signal hits
with σ = 120 eV
(1 e- ~ 3 eV ➔ 40e- noise)

Sum energy in
50x50 µm² cells
E_{sum}

Effect on the energy resolution

- Example for 20 GeV electrons, step by step, in function of the threshold :

VERY PRELIMINARY, with a simple pixel description for the charge spread simulation
Objective is to update for LCWS with detailed simulation of the submitted sensors.

1- Ideal case : geant4 energy

2- after charge sharing

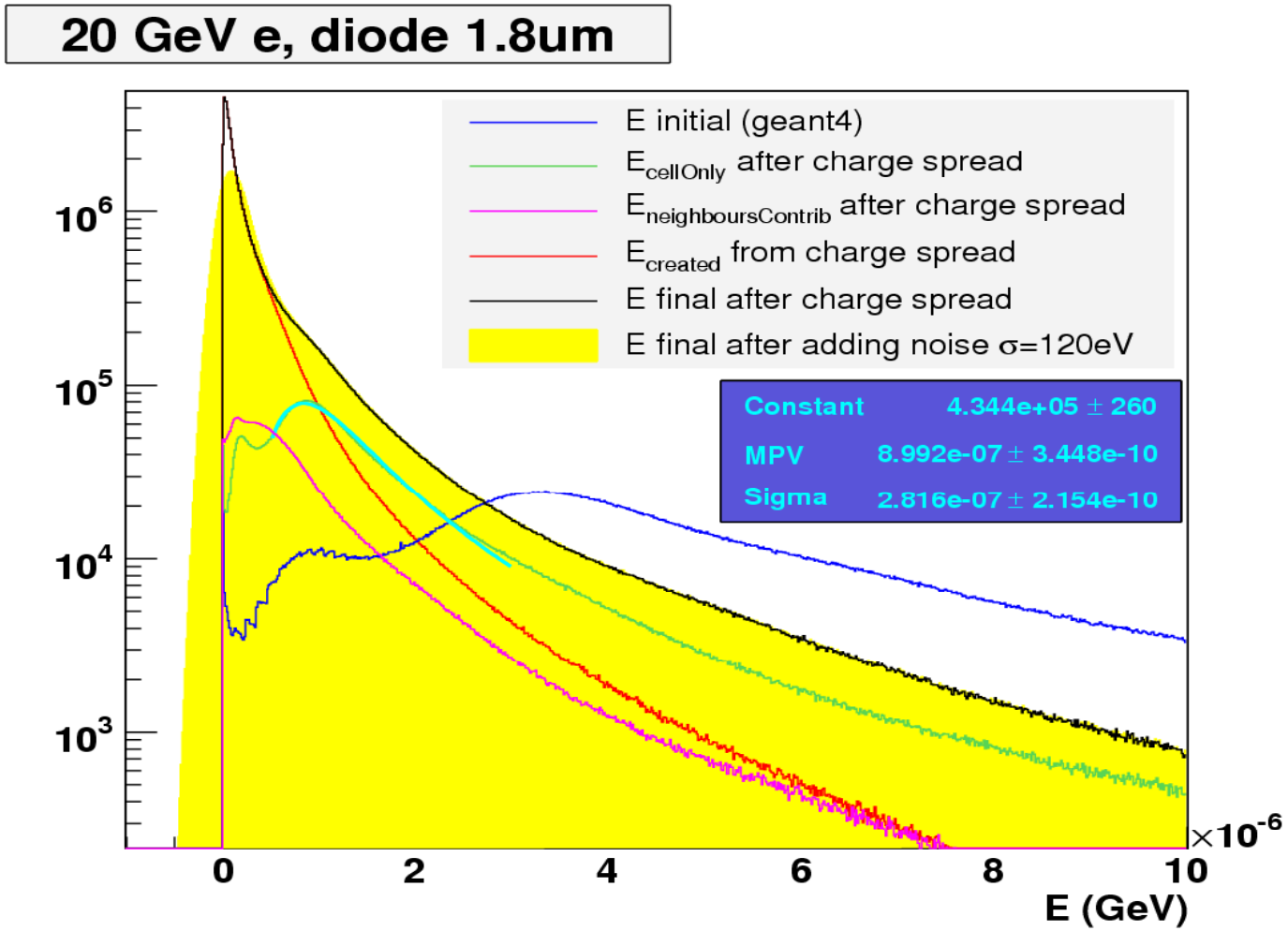
3- after noise adding (currently pessimistic : 40e-)

4- Simple clustering based on closest neighbours

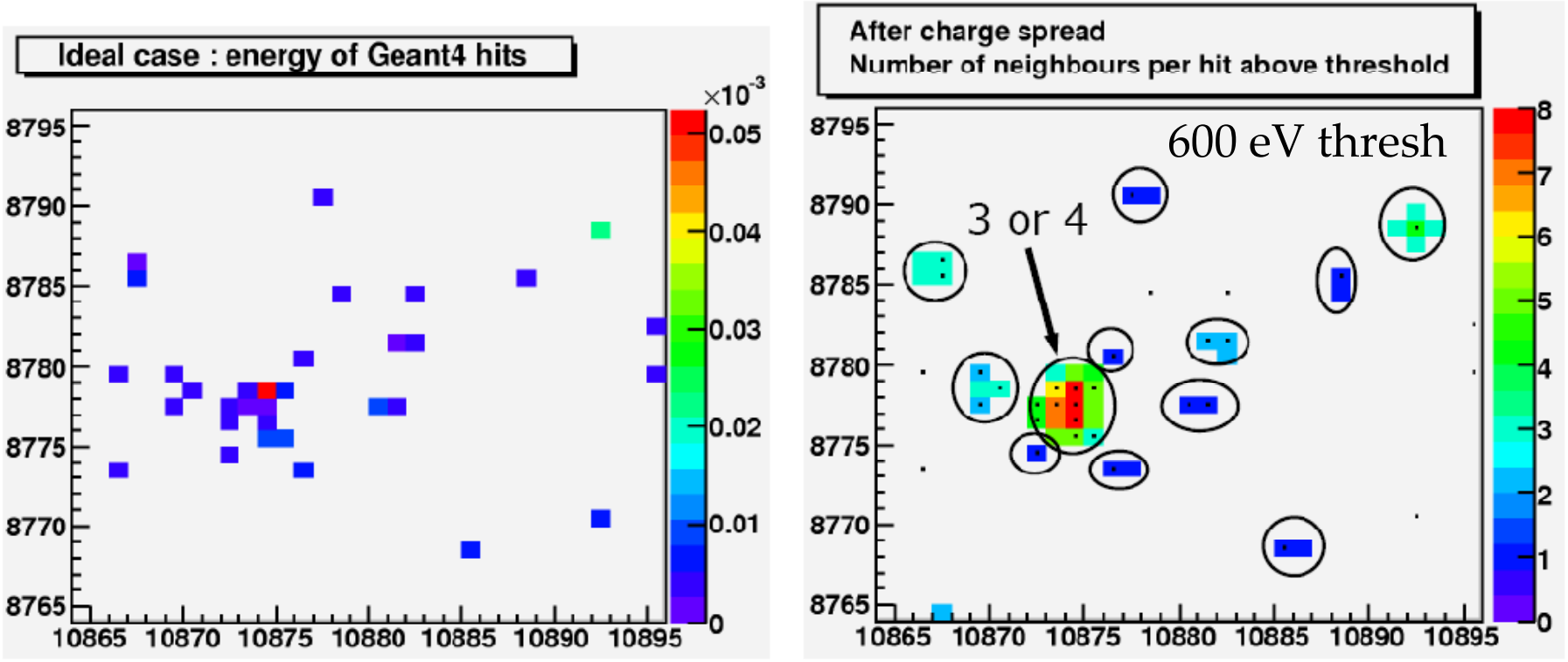
5- after removal of dead area (5 pixels every 42 pixels)

Energy after charge spread and noise without any threshold cut

VERY PRELIMINARY



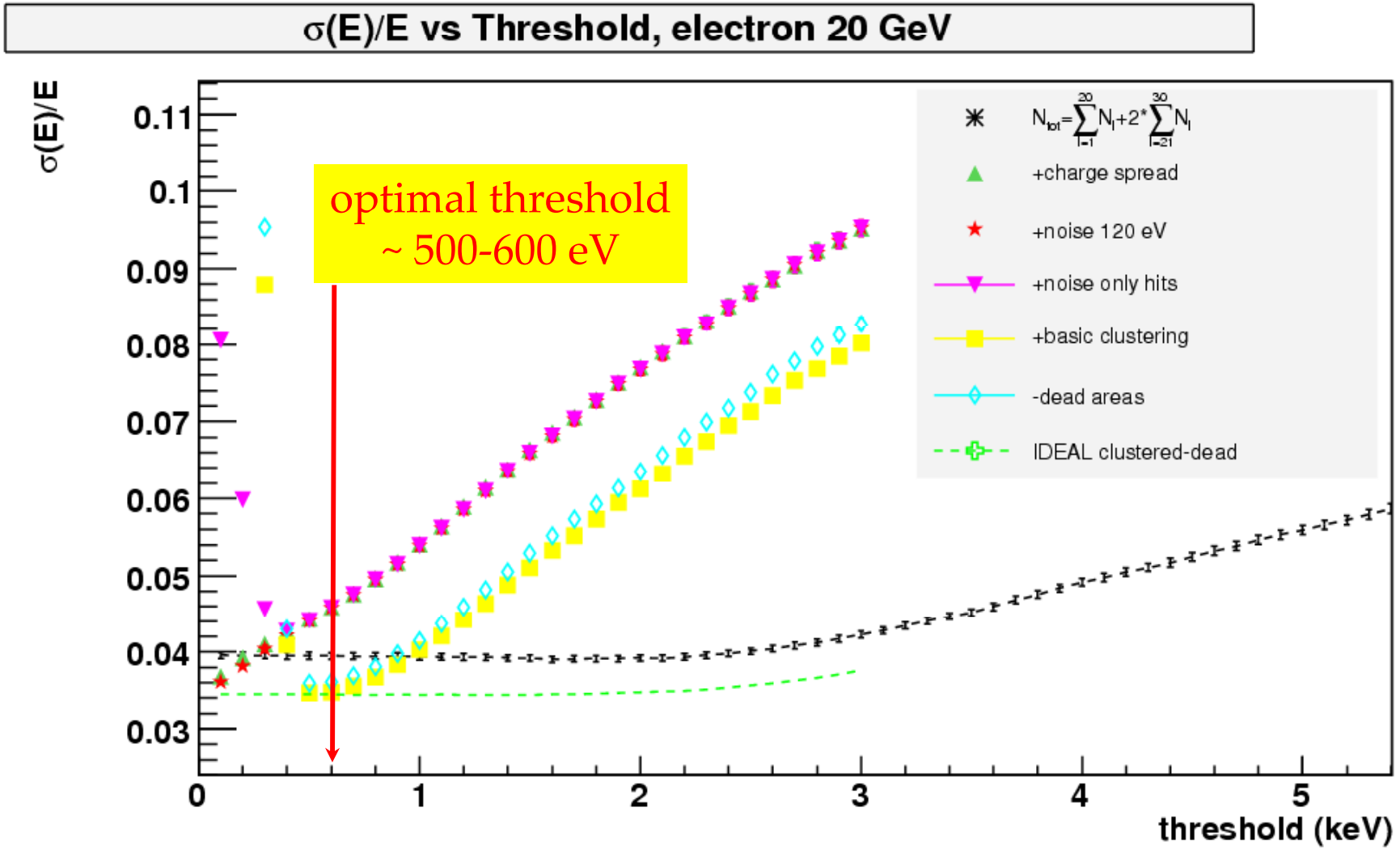
A quick word on the clustering



- 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.

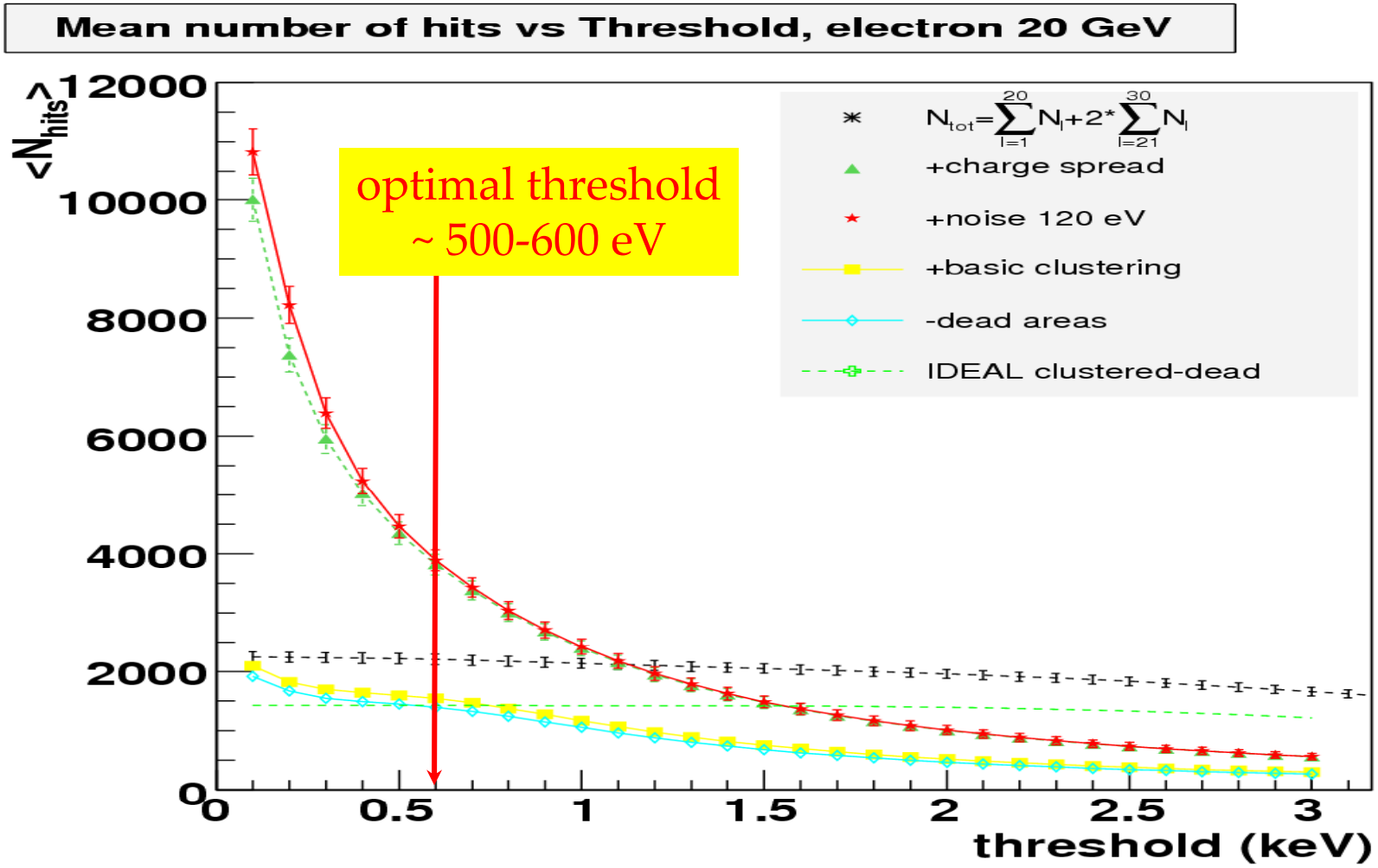
Results on the energy resolution vs threshold after each step

VERY PRELIMINARY



In terms of number of hits

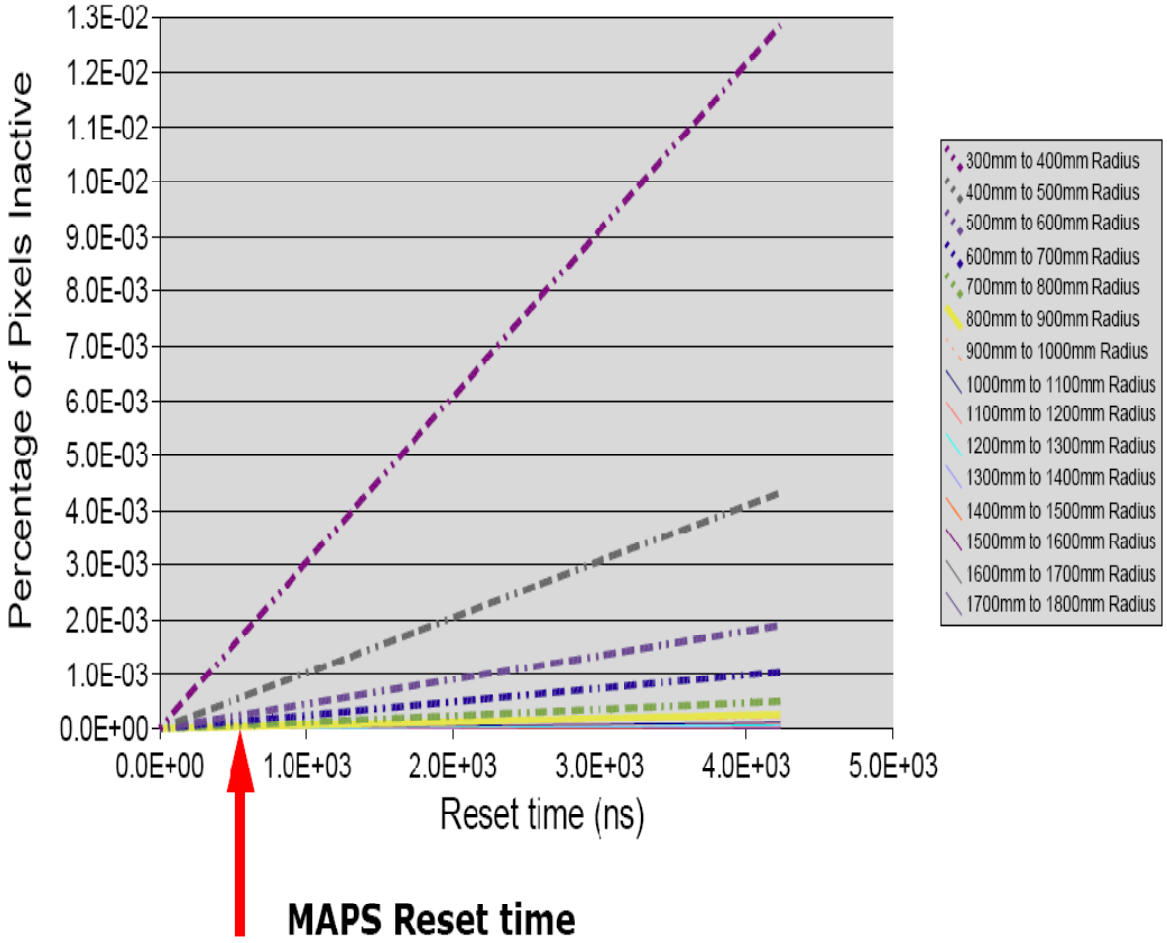
VERY PRELIMINARY

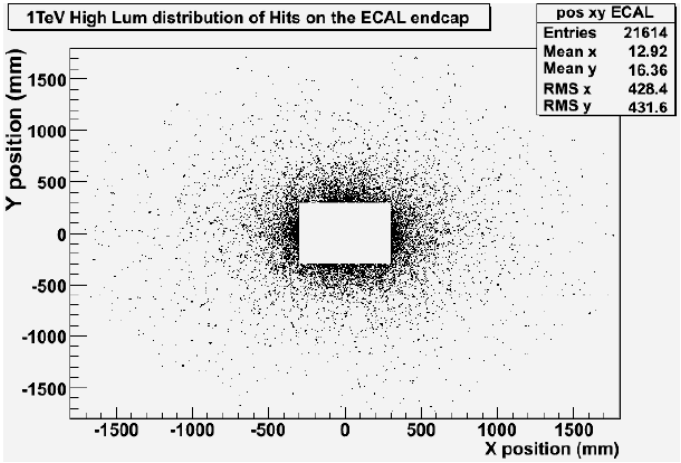


Beam background studies

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

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



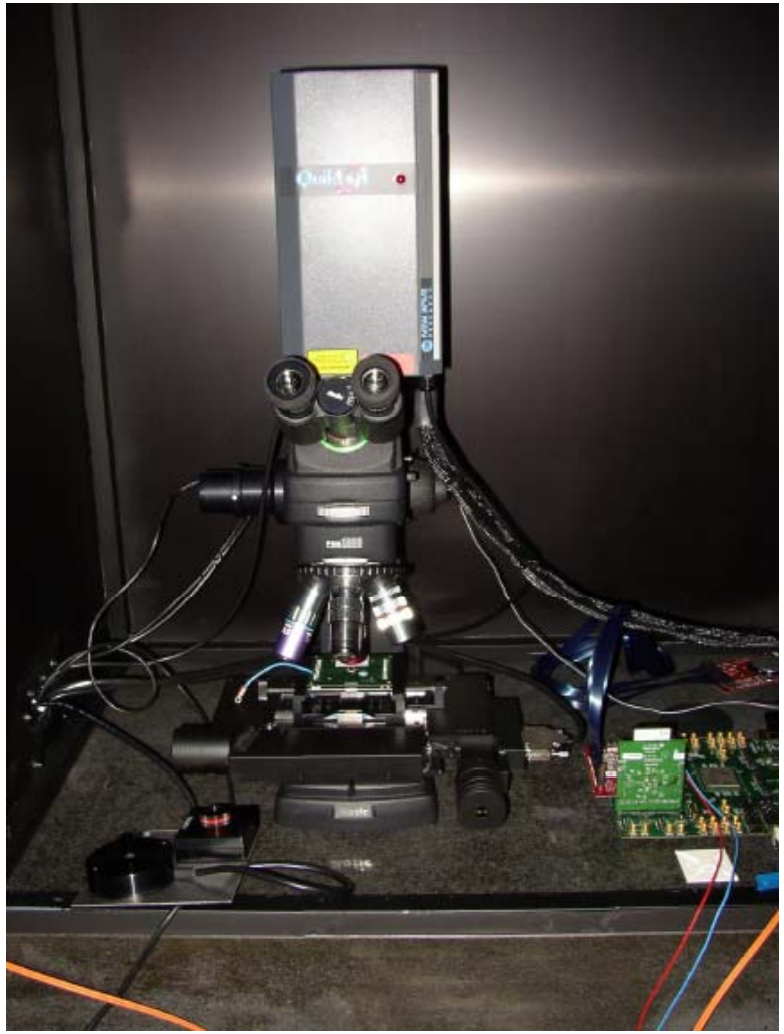


Power issues

- Baseline ECAL target value : 4 μW.mm^{-2}
- Current design v1.0 : 40 μW.mm^{-2}
- BUT v1.0 has been designed for proof of concept and technology ➔ not optimised for power consumption, and not the final product !!
- Options :
  - ✓ 50 →100 μm : factor 4 reduction
  - ✓ longer integration time : up to factor 2 reduction
  - ✓ lower operating voltages : 10% additional reduction

Manufacturing and plans for the summer

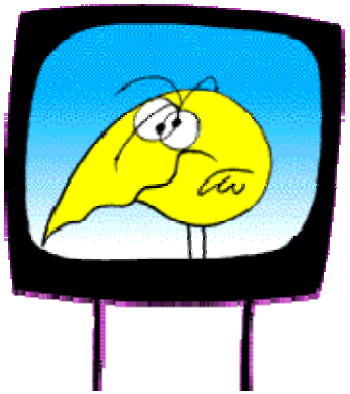
- Sensor has been submitted to foundry on April 23rd.
- Will be back in July : need to be ready immediately for first tests.
- Charge diffusion studies with a powerful laser setup at RAL :
  - 1064, 532 and 355 nm wavelength,
  - focusing < 2 μm,
  - pulse 4ns, 50 Hz repetition rate,
  - fully automatized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



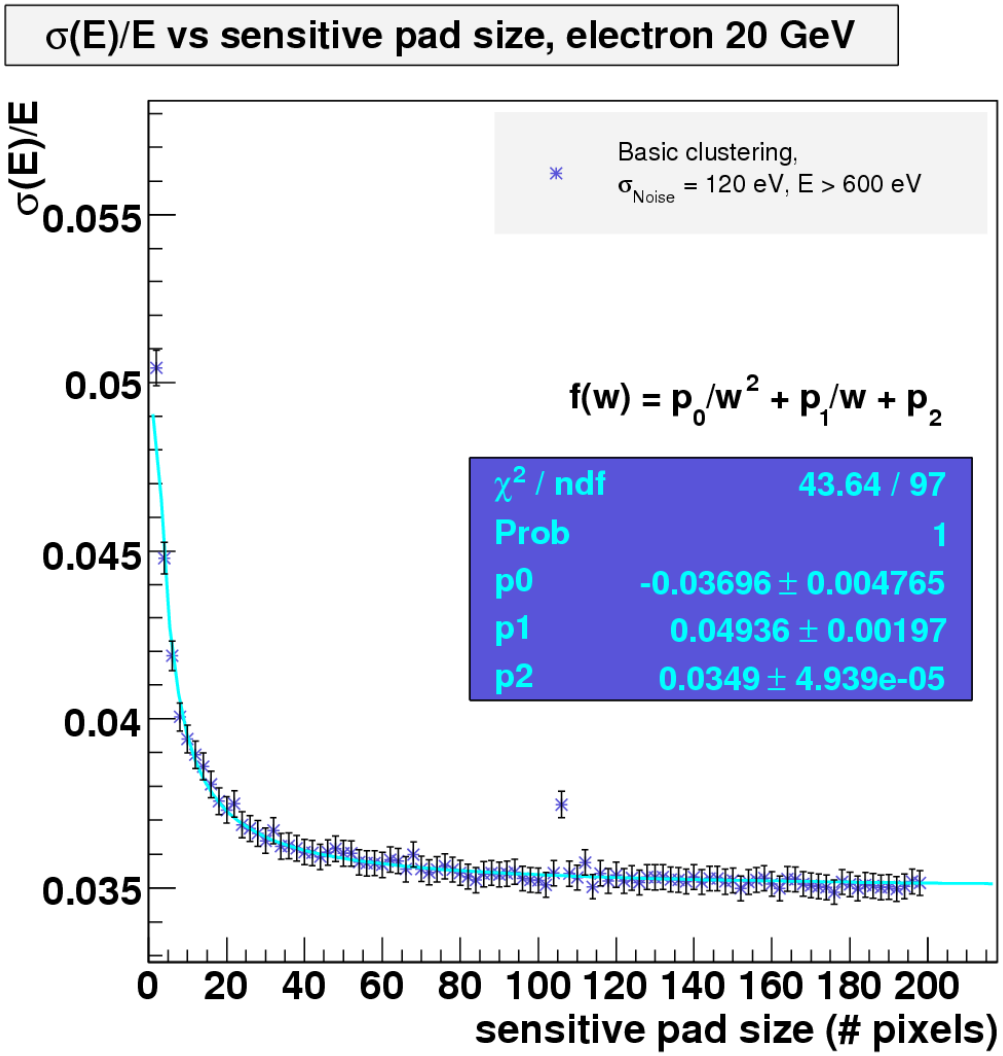
Conclusion and longer term : sensor v2.0

- Looking forward to have the sensor back, and we will be ready to have results ASAP !
- Design is far from being optimised, but we will learn a lot from it : charge spreading and collection efficiency studies, cosmics (and testbeam at Desy ??) and radioactive source studies.
- After detailed studies of the first setup, and careful comparison of the charge simulation and digitisation results with reality : will design a second round, with optimisation of parameters, e.g. sensor size, diodes placement, and issues like power consumption addressed.
- Size of the second setup : 2*2 cm^2 (no stitching yet)
- Timescale : summer 2008

Thank you for your attention



Influence of dead width



$\sigma(E)/E = a/\sqrt{E}$

➔ $a = 0.1561$ asymptotical value

➔ $a = 0.161$ @ 42 sensitive pixels