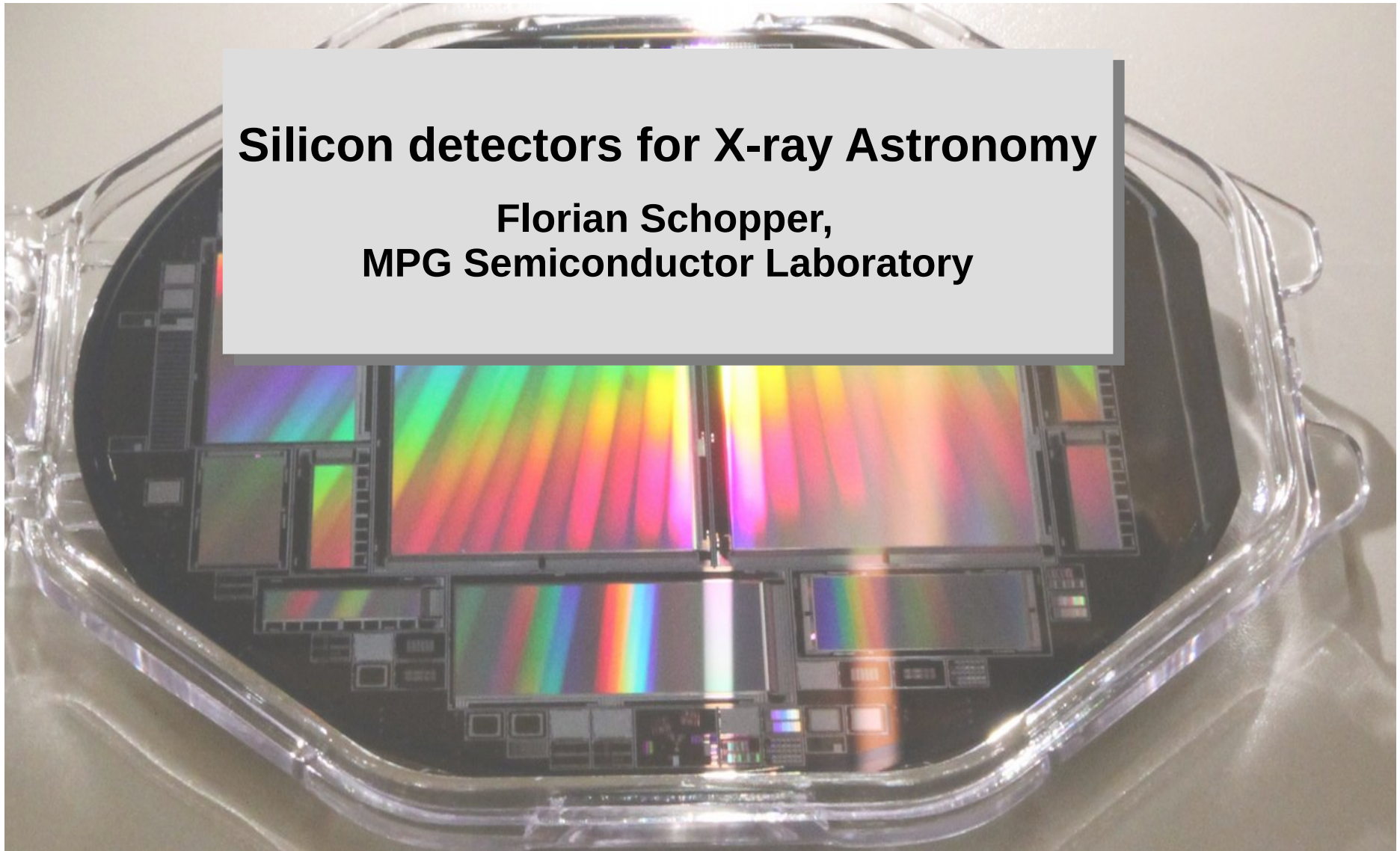




Silicon detectors for X-ray Astronomy

Florian Schopper,
MPG Semiconductor Laboratory





- Intro HLL, projets actuels
- les principes des détecteurs à HLL
- Retouches des principes pxd
- Retouches des principes ccd
- Combinaison du sdd avec strips



Max-Planck Semiconductor Laboratory



Le bâtiment actuel à Neuperlach (Siemens)



~40 personnes travaillent actuellement à HLL.

Un atelier pour les expériences de la MPG et pour instituts extérieurs.

Le nouveau bâtiment à Garching (MPG)
déménagement Nov 2023

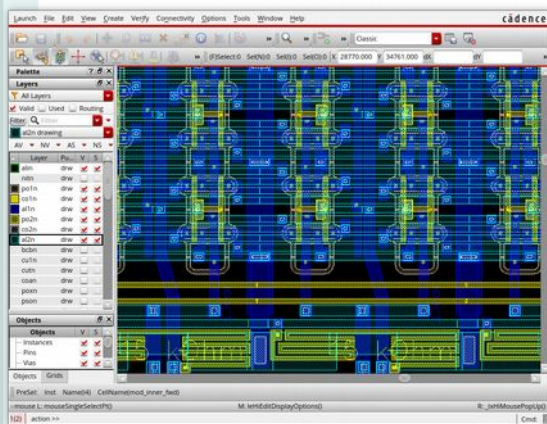
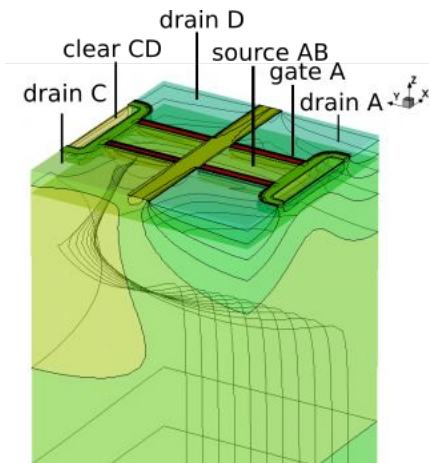




Laboratoire Semiconducteurs de Max-Planck: ce qu'on fait



Simulation et design

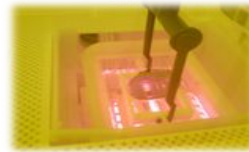


production

Ion-implantation



wet chemistry

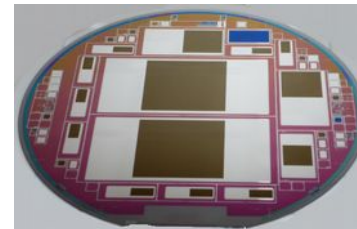


Test + analyses

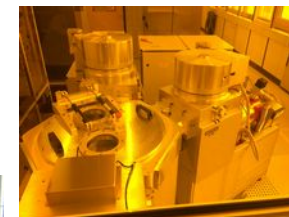
thermal



Inspection



Plasma



lithography



Couper + monter



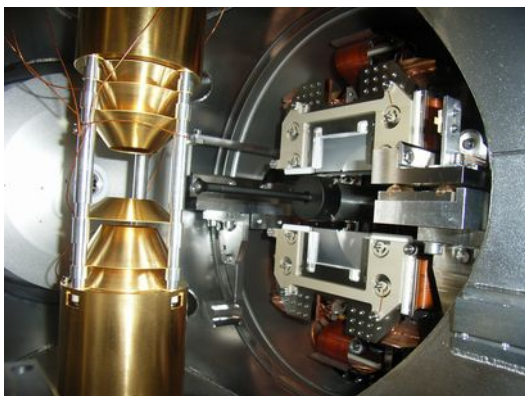
+ nouveaux: CMP
e⁻ beam litho



Utilisation terrestre



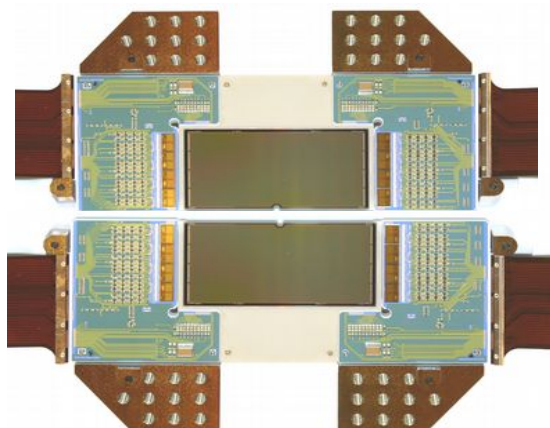
CCDs at FLASH



BELLE II **Pixel Vertex Detector** at KeK



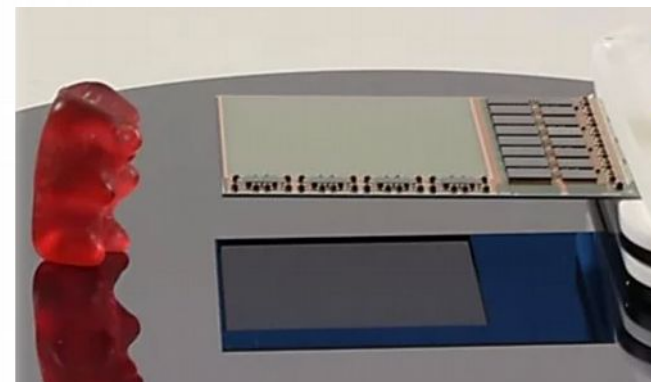
LAMP **CCDs** at SLAC



TRISTAN: 3486 **Silicon Drift Detectors** for electron counting



Pixel Electron Imaging Sensor
Edet 80k Framerate, 30 μ m

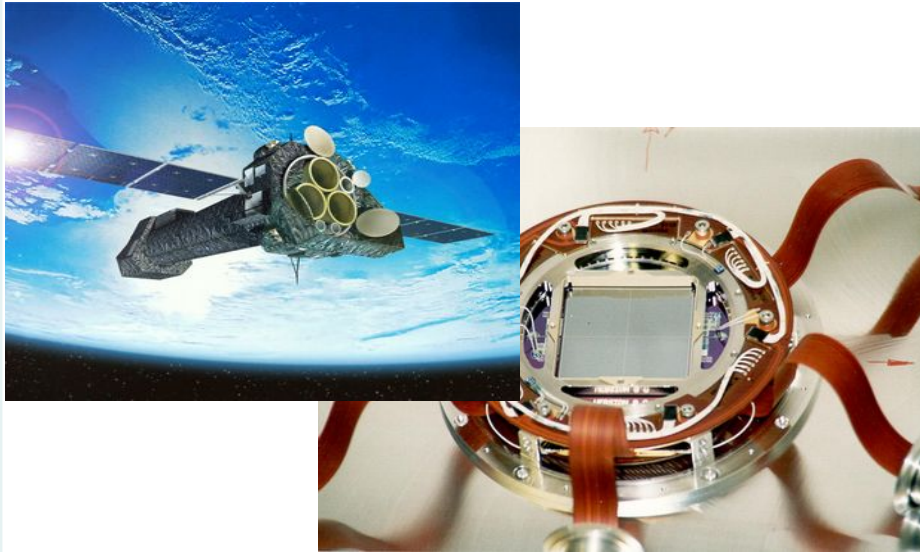




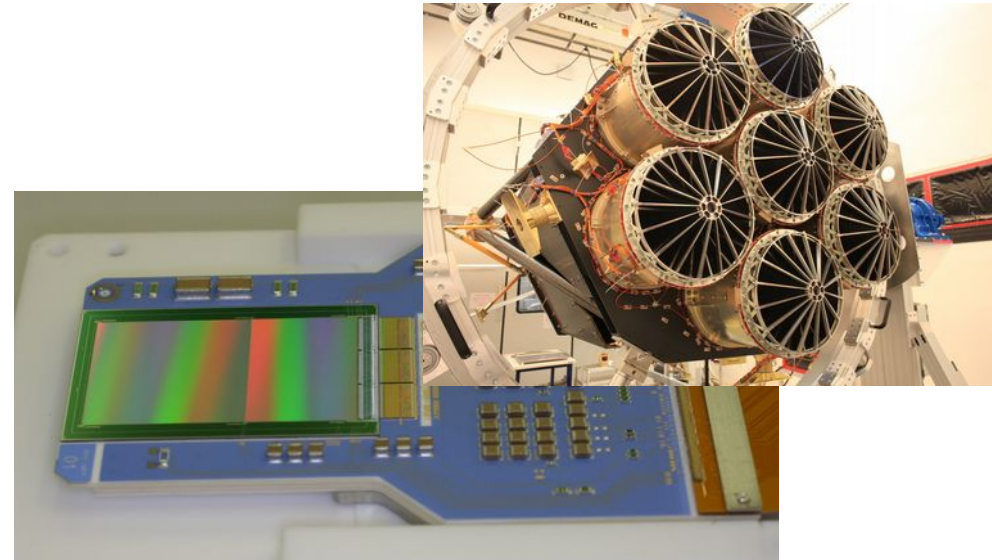
Utilisation en espace



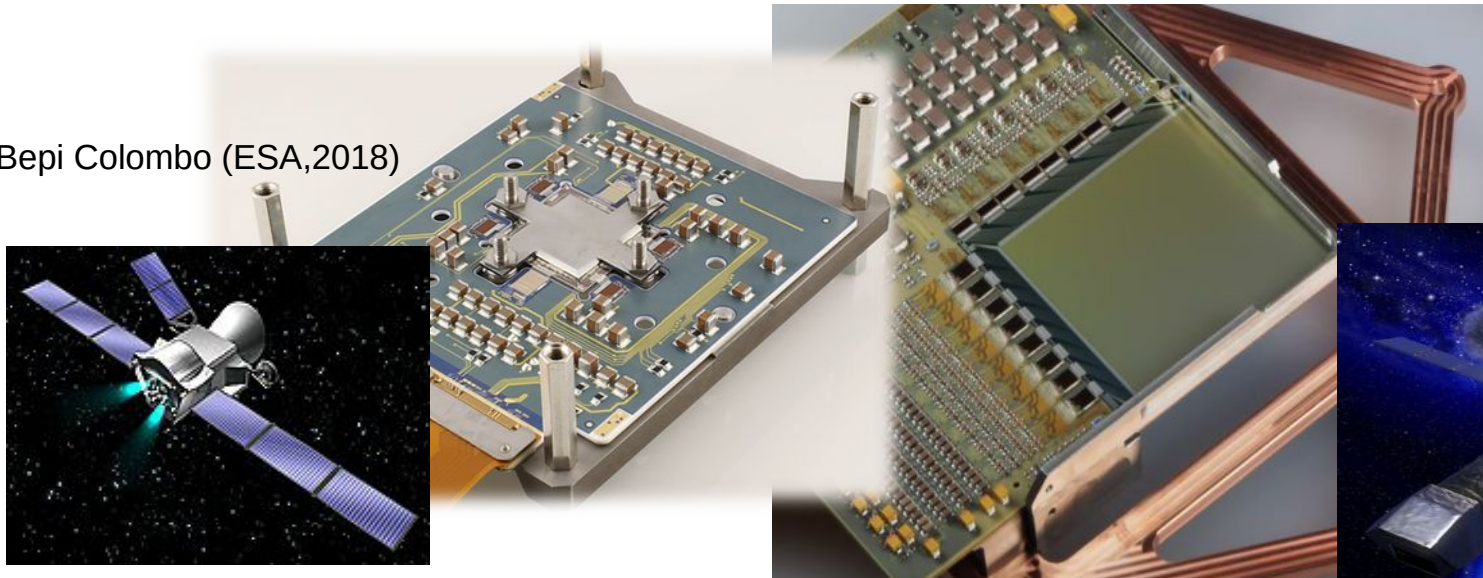
XMM-Newton (MPE/ ESA, 1999)



eROSITA (MPE/DLR, 2019)



Bepi Colombo (ESA, 2018)



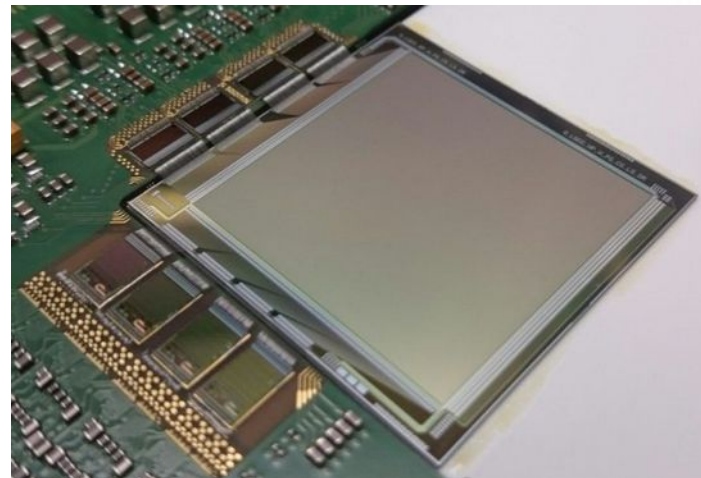
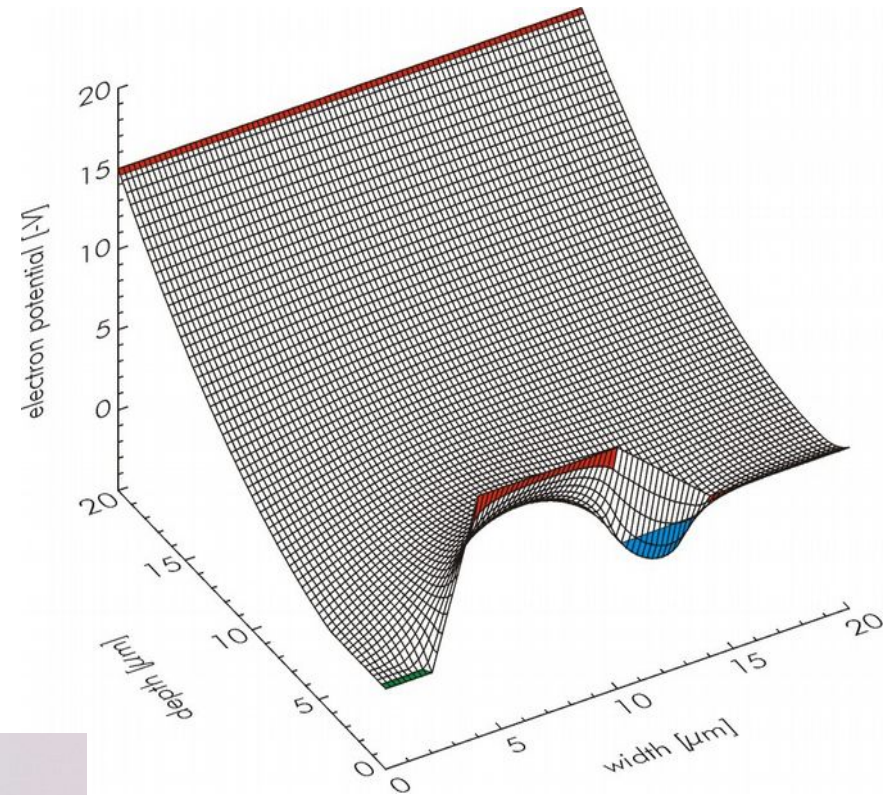
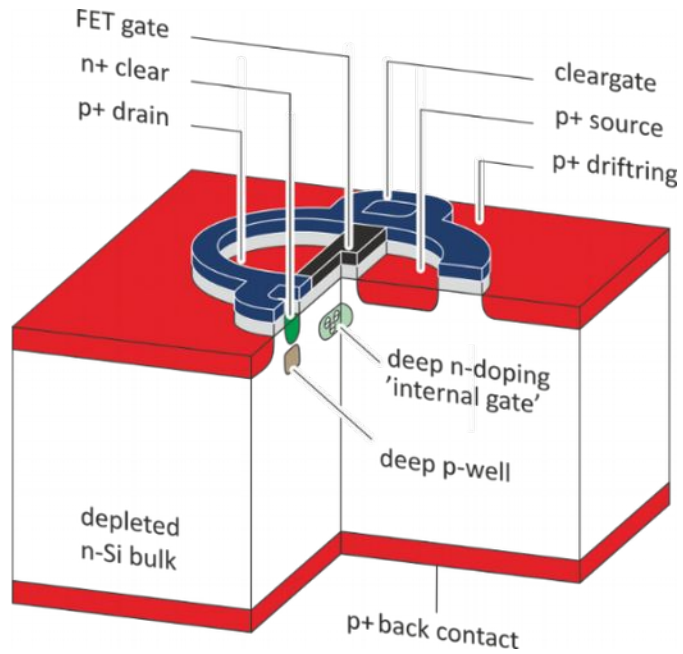
ATHENA (MPE/ESA, 2031)





DepFET Pixel Matrix

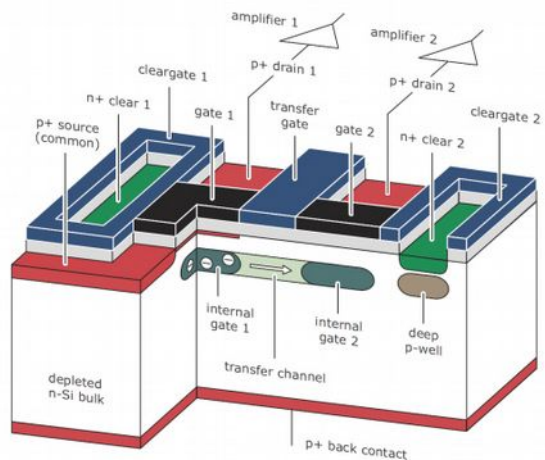
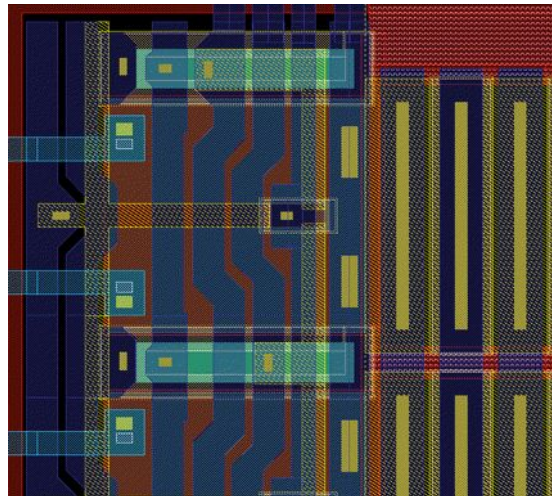
Une cellule:



ATHENA (ESA), prototype wide field Imager

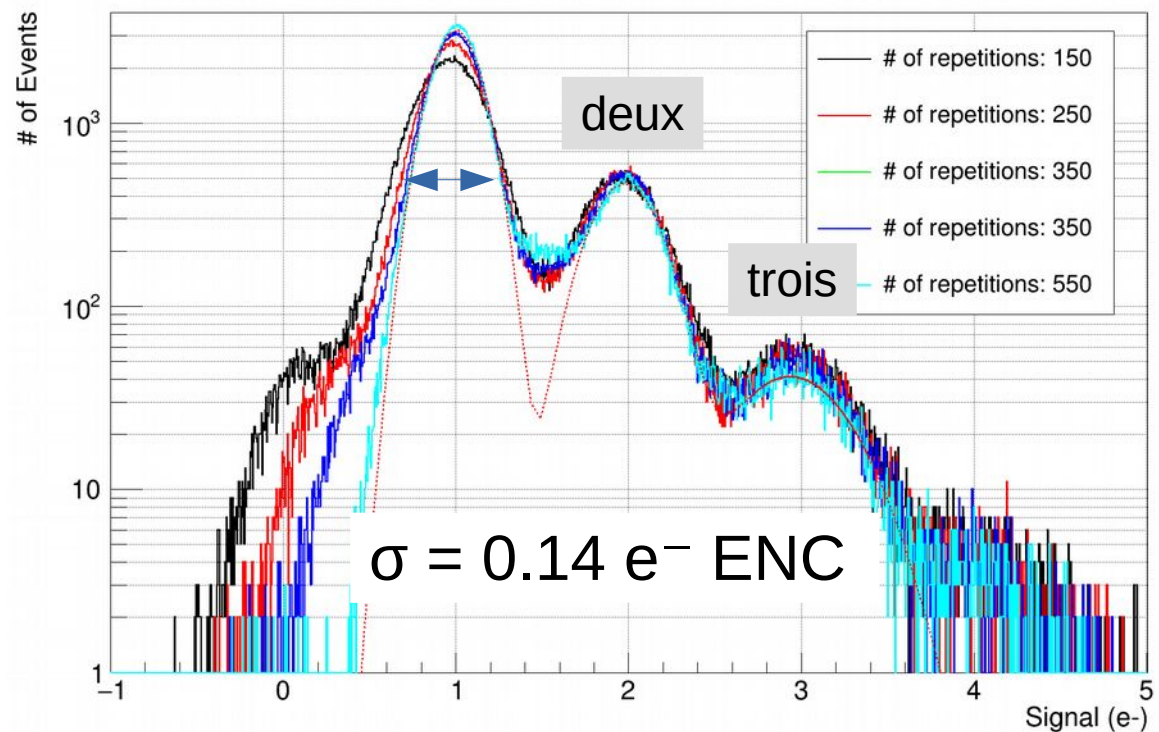


lecture à plusieurs fois répétée sans détruire le signal



En mesurant la charge collectée plusieurs(n) fois,
le „bruit effectif“ est réduit par $1/n$.

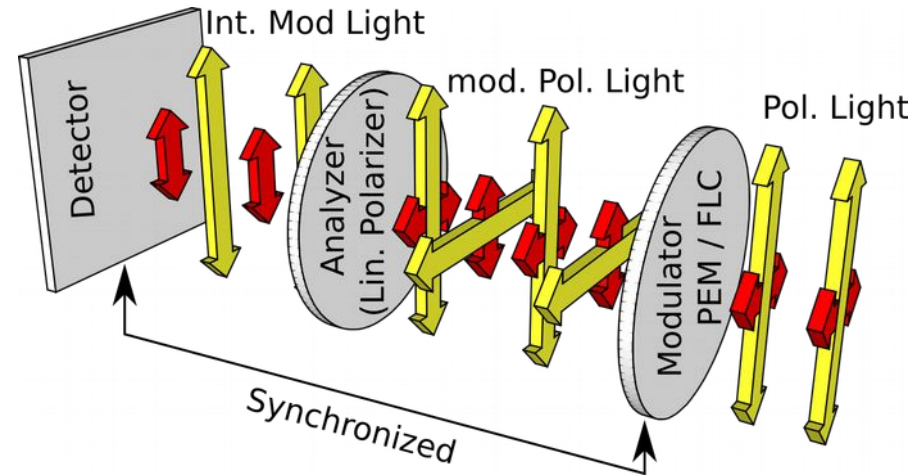
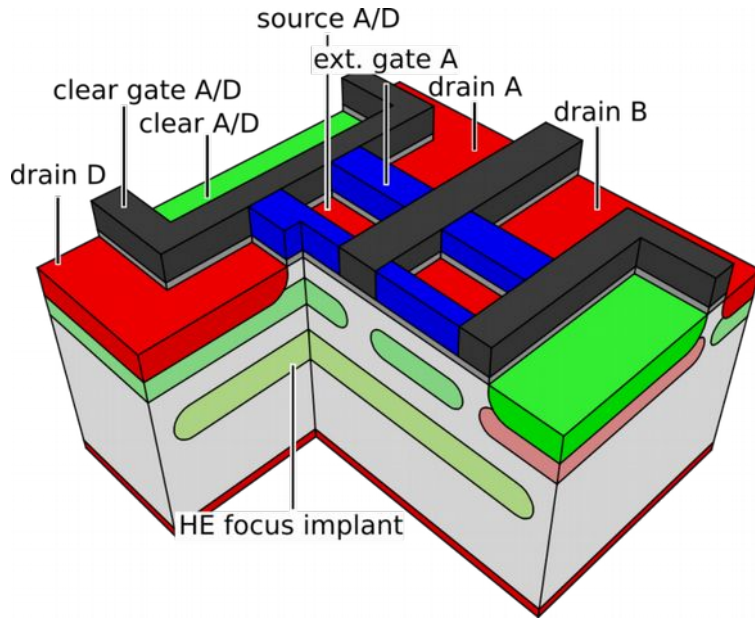
Un electron singulier



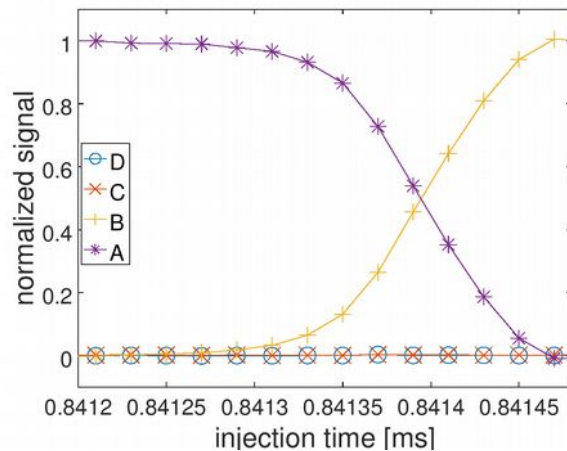
Published [preprint: [scipost 202211 00018v2](https://arxiv.org/abs/202211.00018v2)]



Quadropix pour imageurs de polarisation



Select storage (A;B;C;D) within 100ns



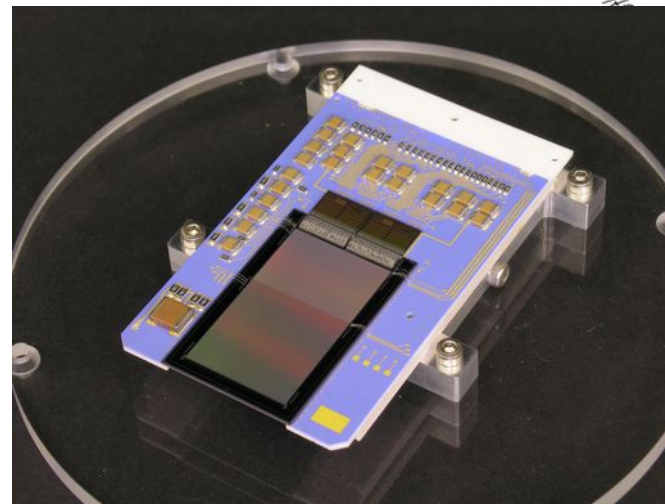
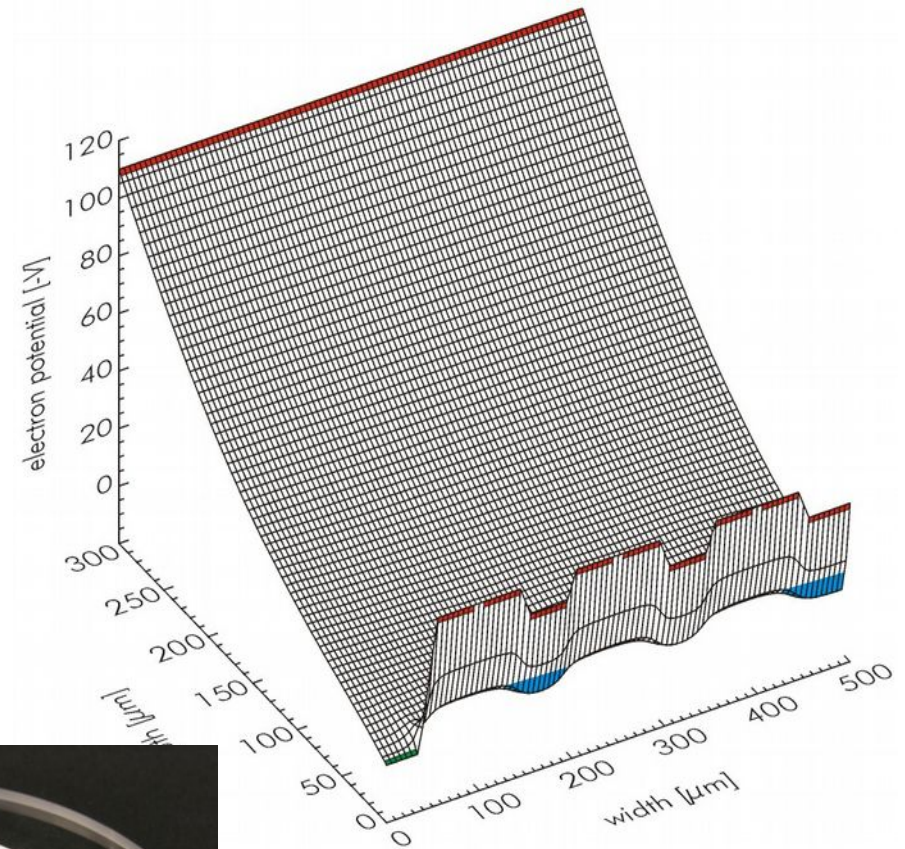
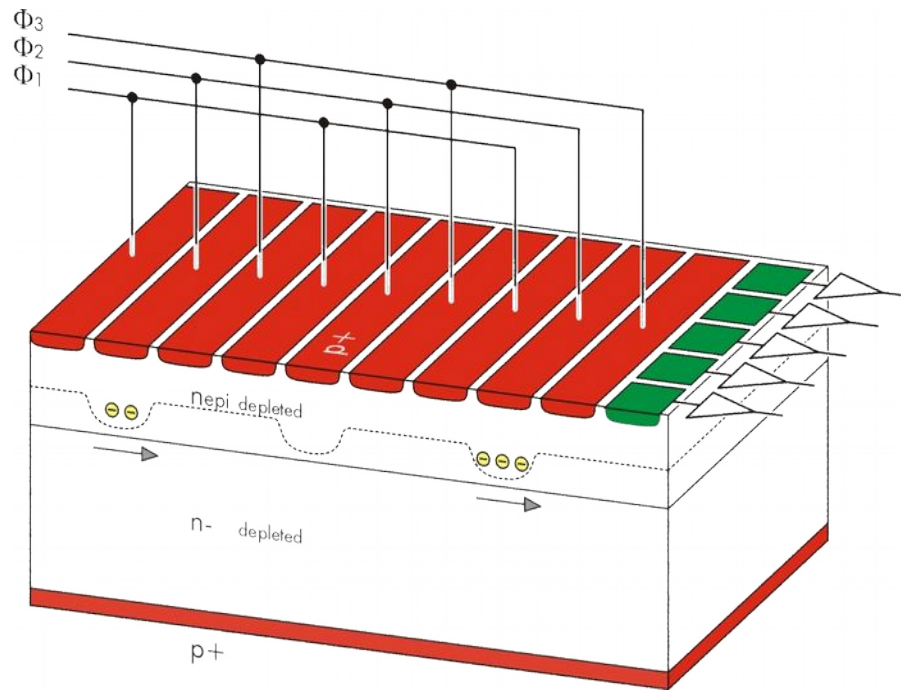
$$\text{Intensity} = \begin{matrix} \text{Green} \\ \text{Red} \end{matrix} + \begin{matrix} \text{Red} \\ \text{Green} \end{matrix} = \text{Grayscale}$$

$$\text{Polarization} = \begin{matrix} \text{Green} \\ \text{Red} \end{matrix} - \begin{matrix} \text{Red} \\ \text{Green} \end{matrix} = \text{Grayscale}$$

4 time-selected images -> 4 Stokes Vektors



pn- Charge Coupled Device



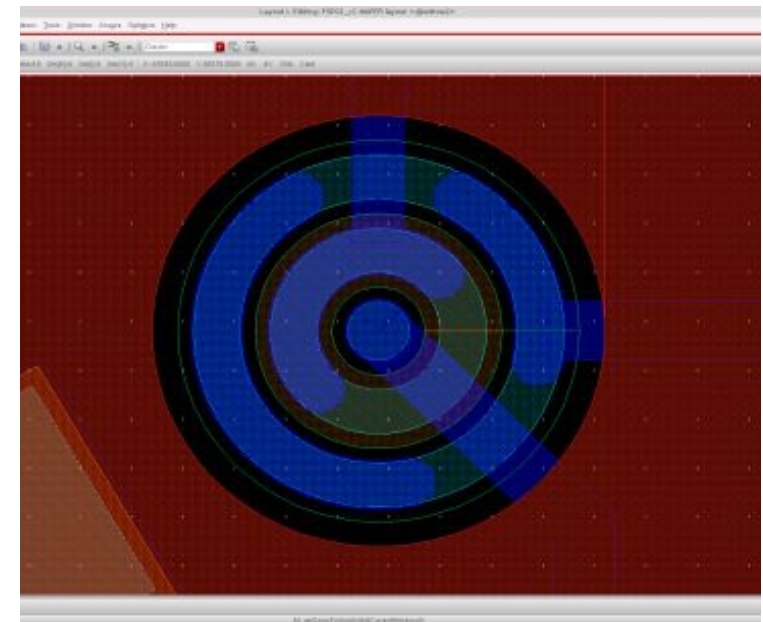
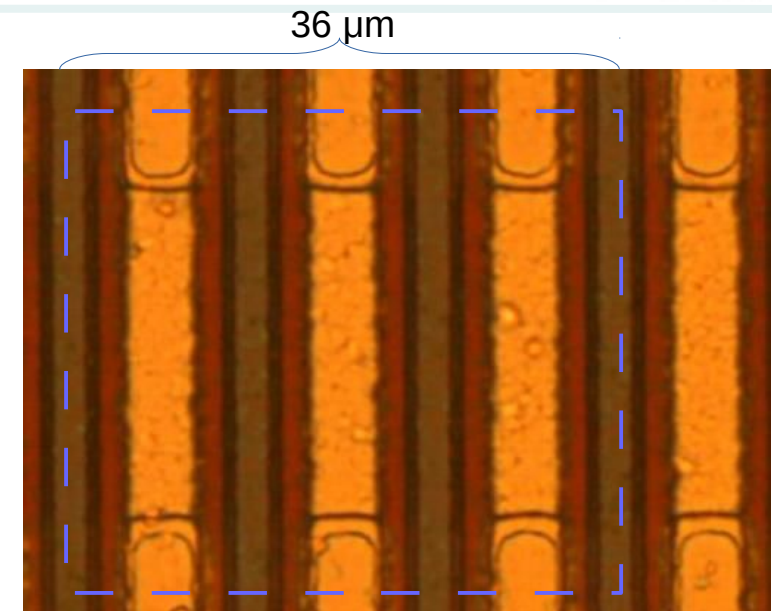


Améliorations pour obtenir des pixels plus petits



★ **Couplage capacitif de lignes MOS**
pour réduire la capacité entre registres.

★ **JFETs plus petits**
capacité réduite, amplification grandie.

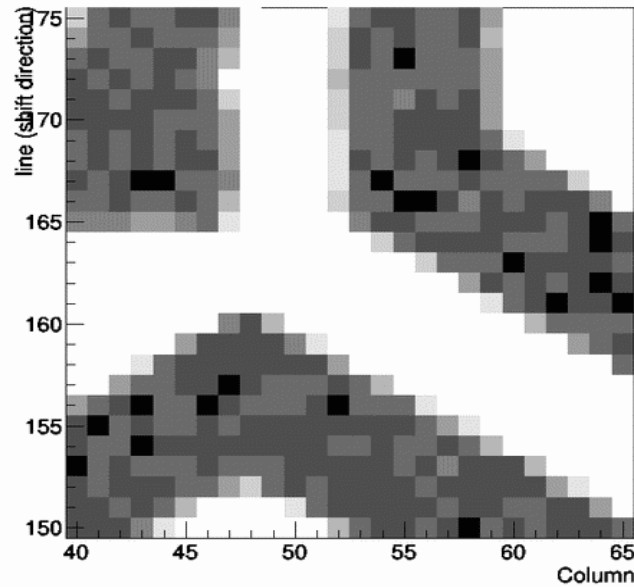




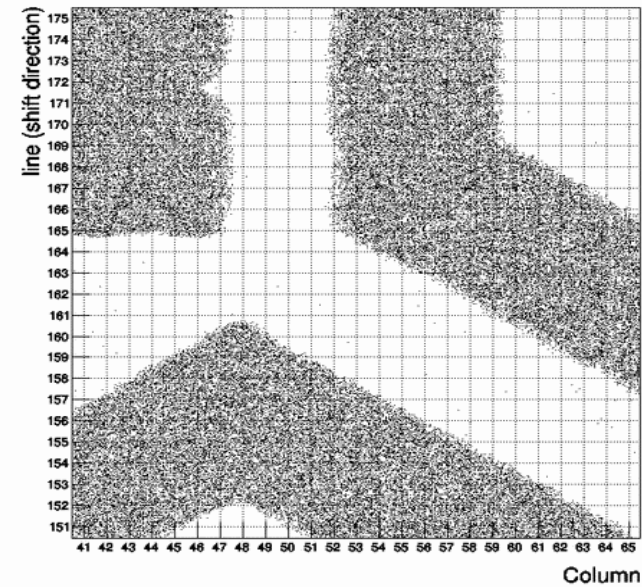
résolution de position



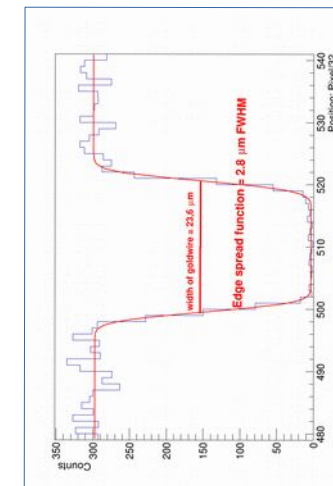
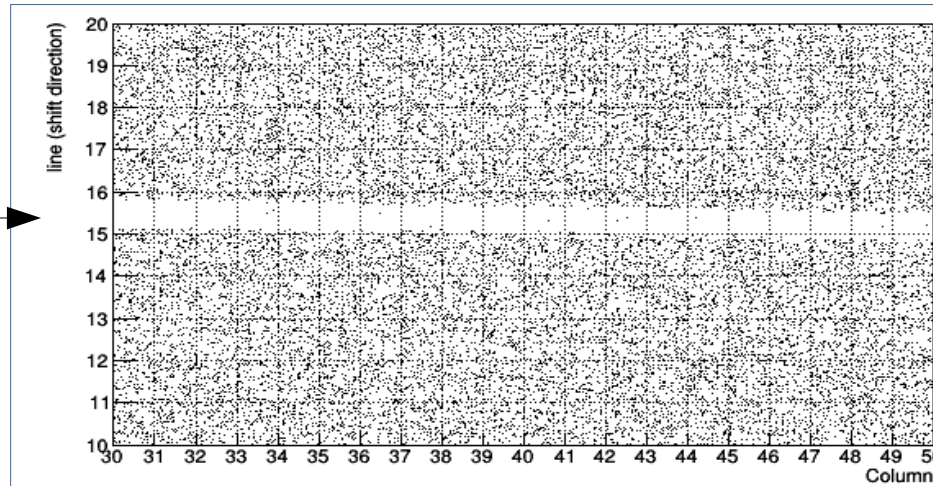
CCD pixels



hit positions placed on 32x32 Subgrid



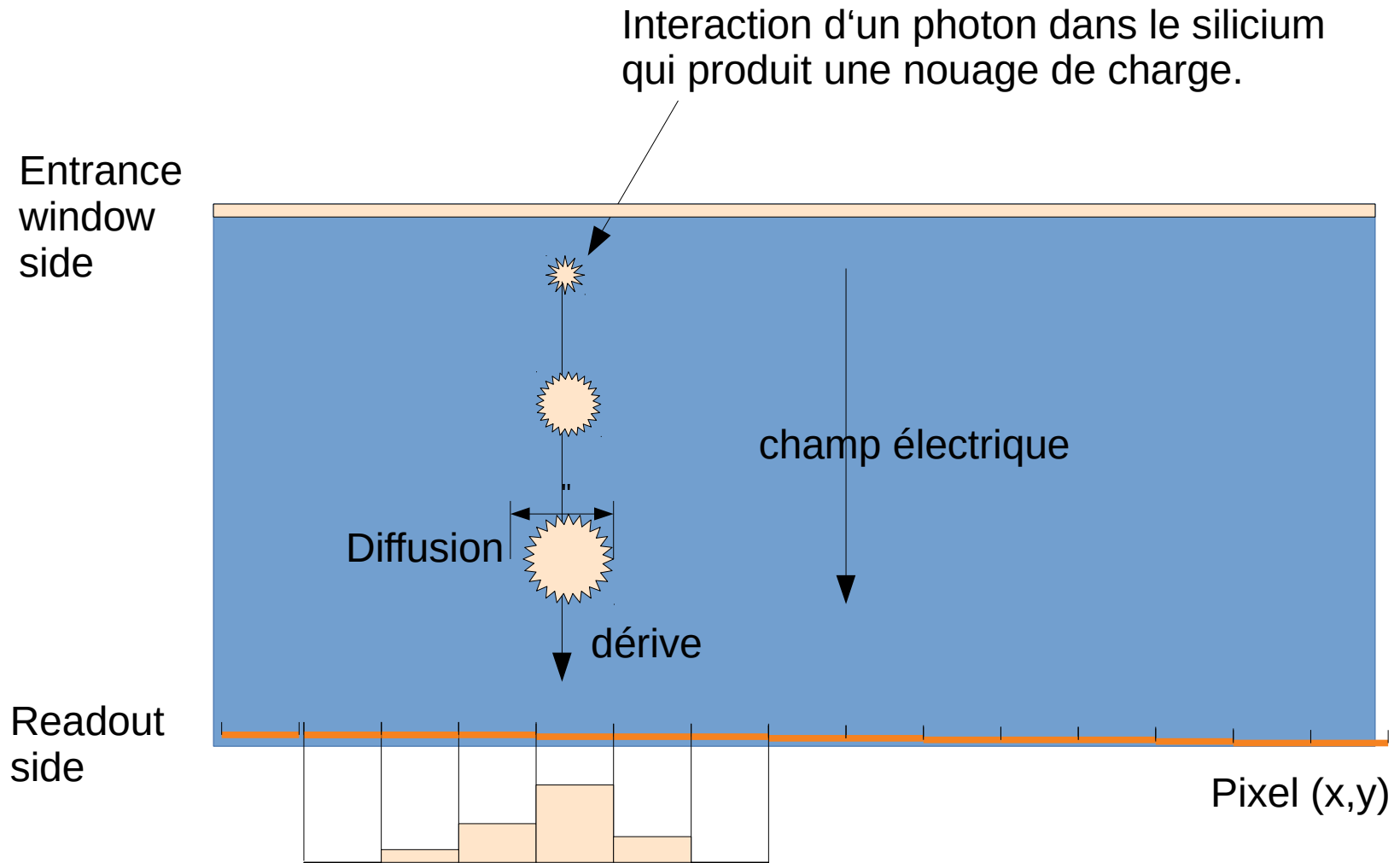
Goldwire
24 μm
diameter



$\sigma = 1.2 \mu\text{m}$



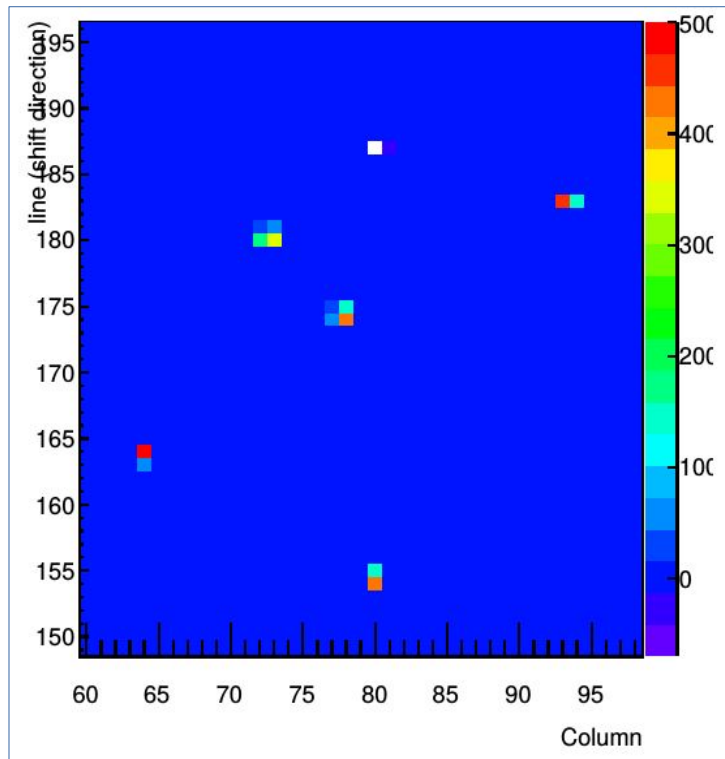
Interpolation de position par distribution de charge



Point like charge is distributed over n pixels



Distribution de charge sur pixels: „charge collection function“

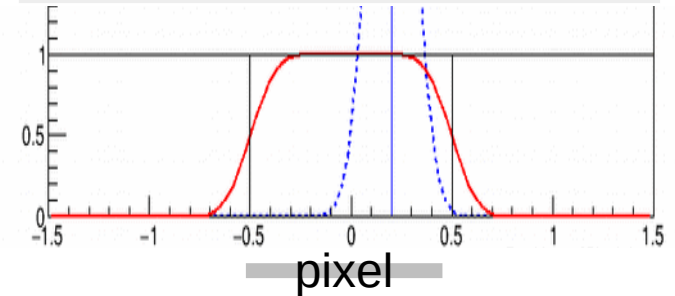


Avec pixels de 36 μm , tous les événements sont visibles dans plusieurs pixels.

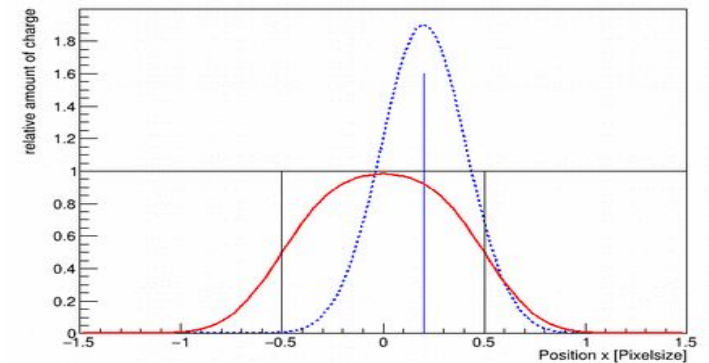
Distribution de charge (normalisé)
Part accumulé dans le pixel

Pixels:

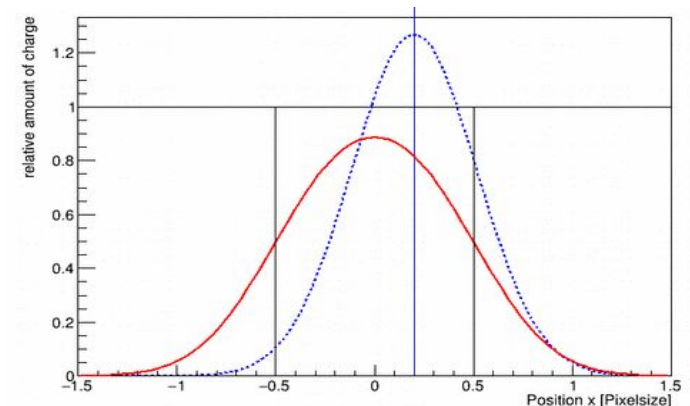
75 μm



36 μm



24 μm





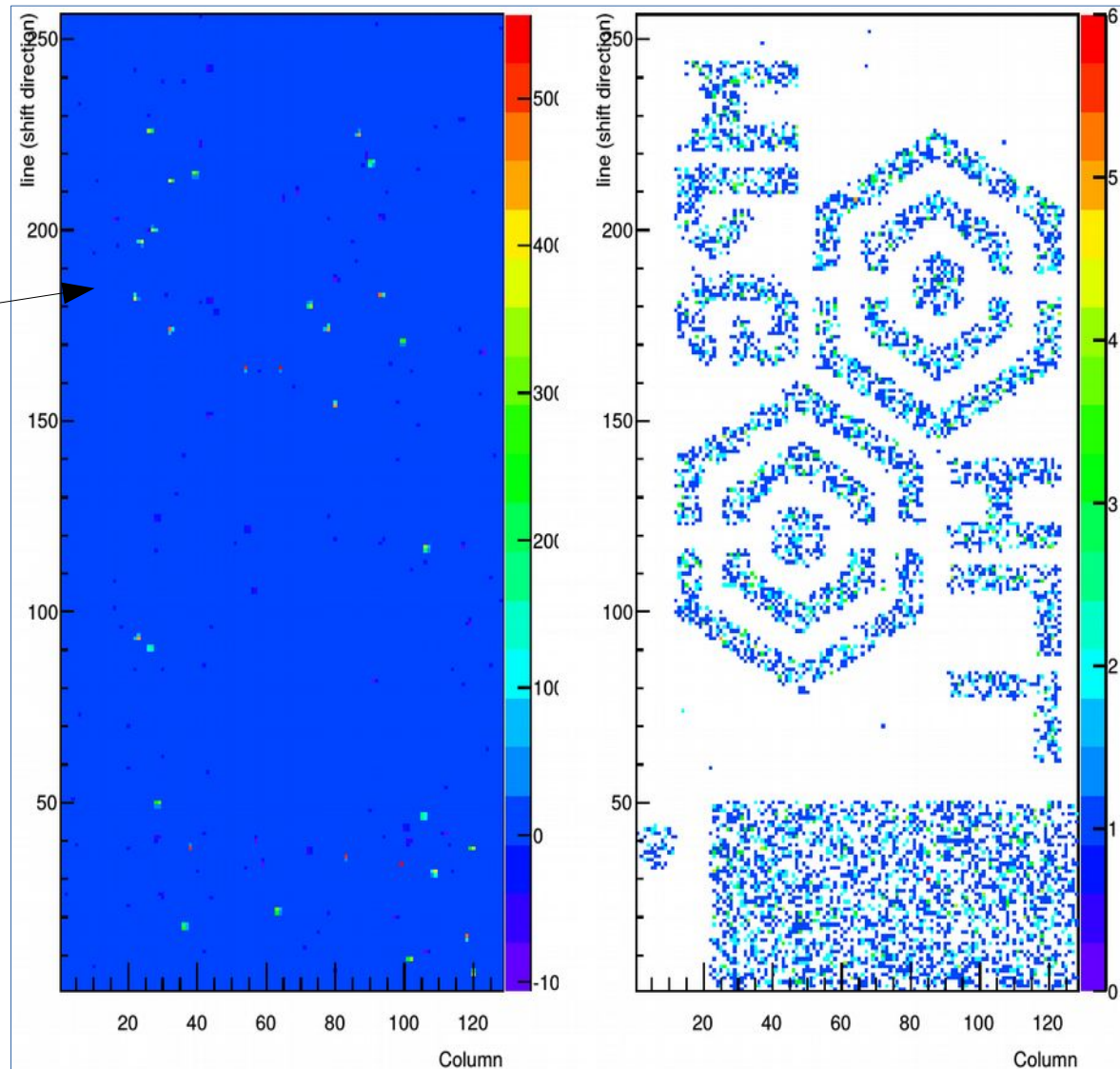
Formation des Images Spectroscopiques



Une trame singulière

Image formée par addition des trames de pixels

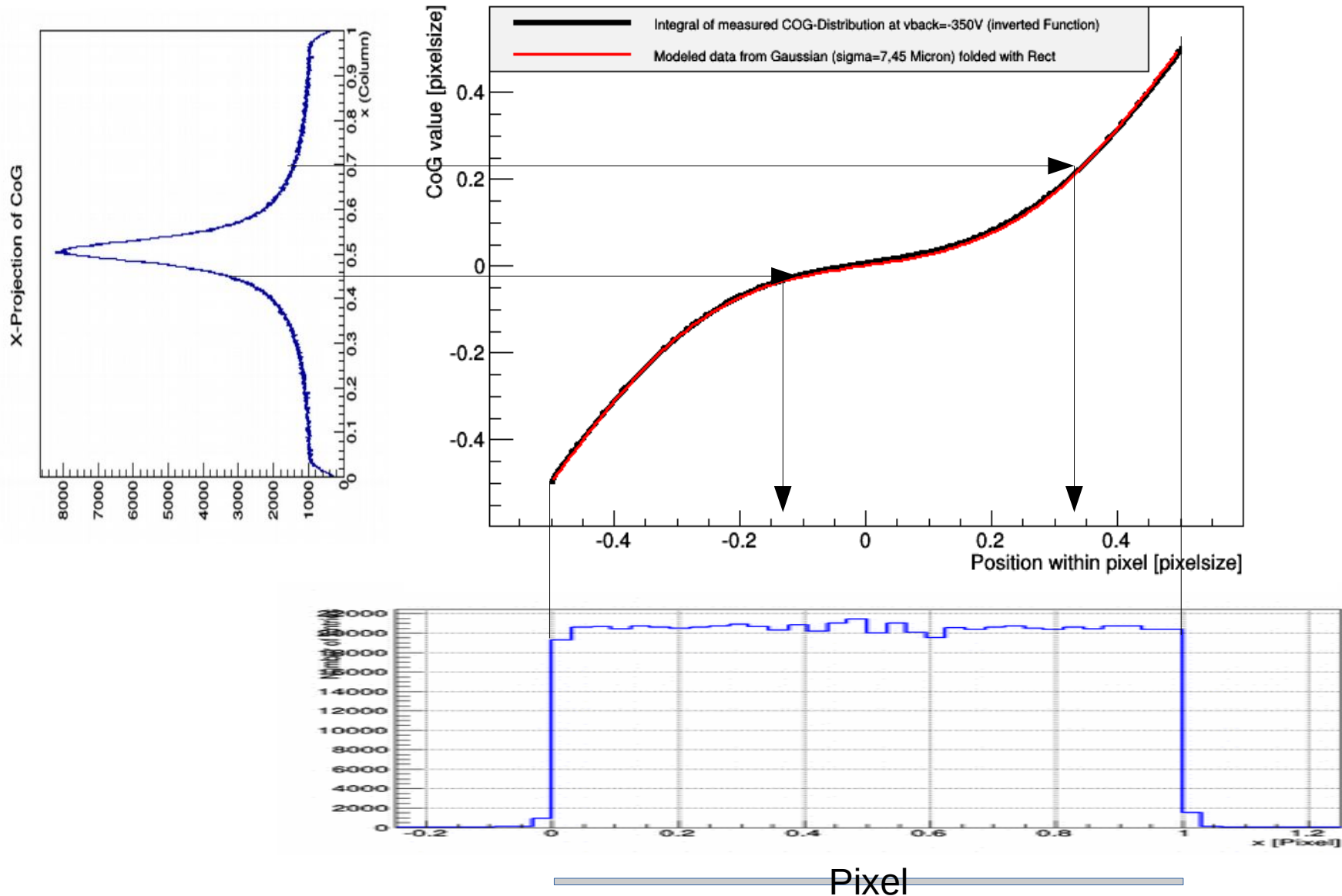
coups,
Événements,
Photons





Correction du centre de gravité (CoG)-> position d'interaction

La distribution du CoG est invertée et chaque évènement est repositionné

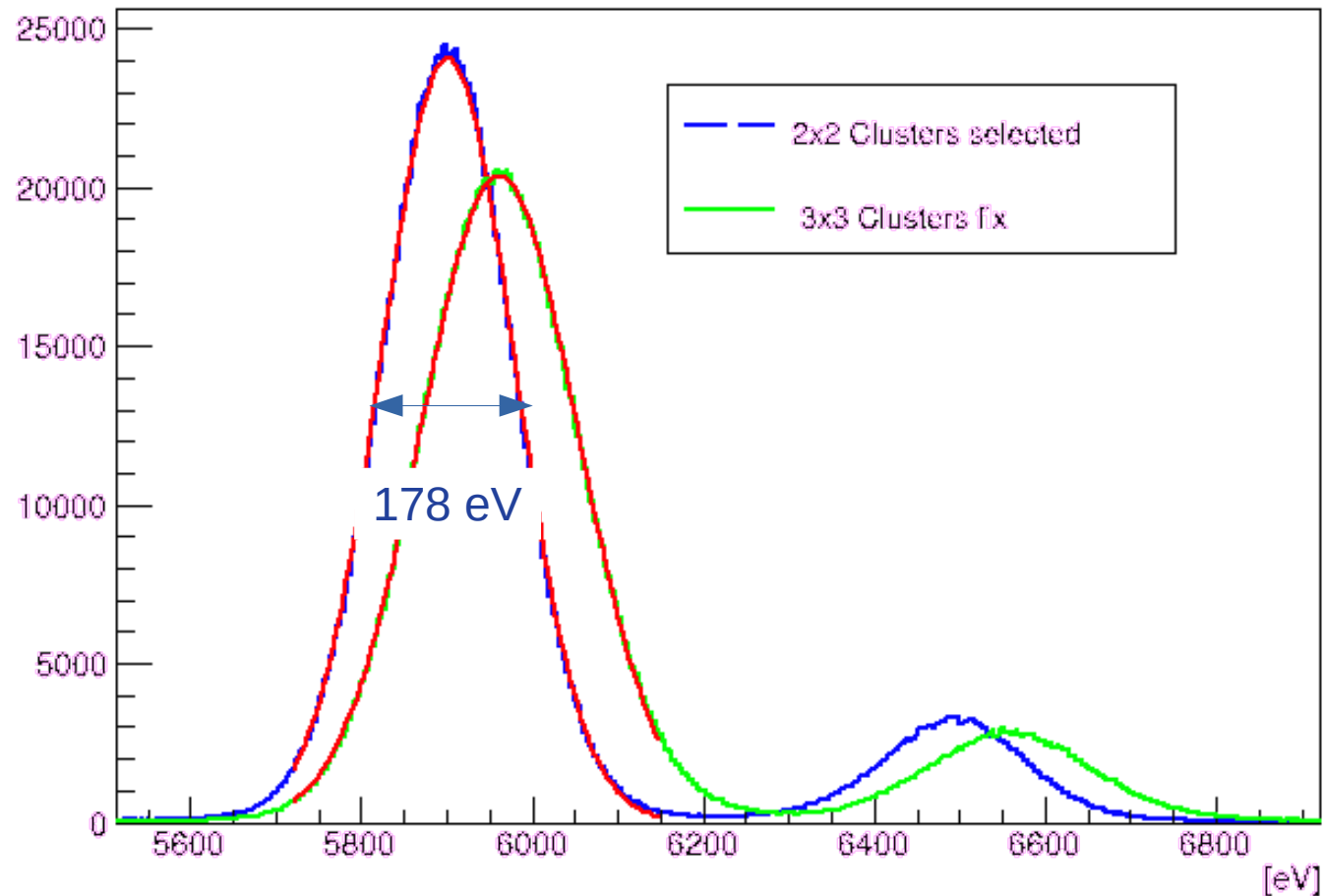




Resolution spectrale

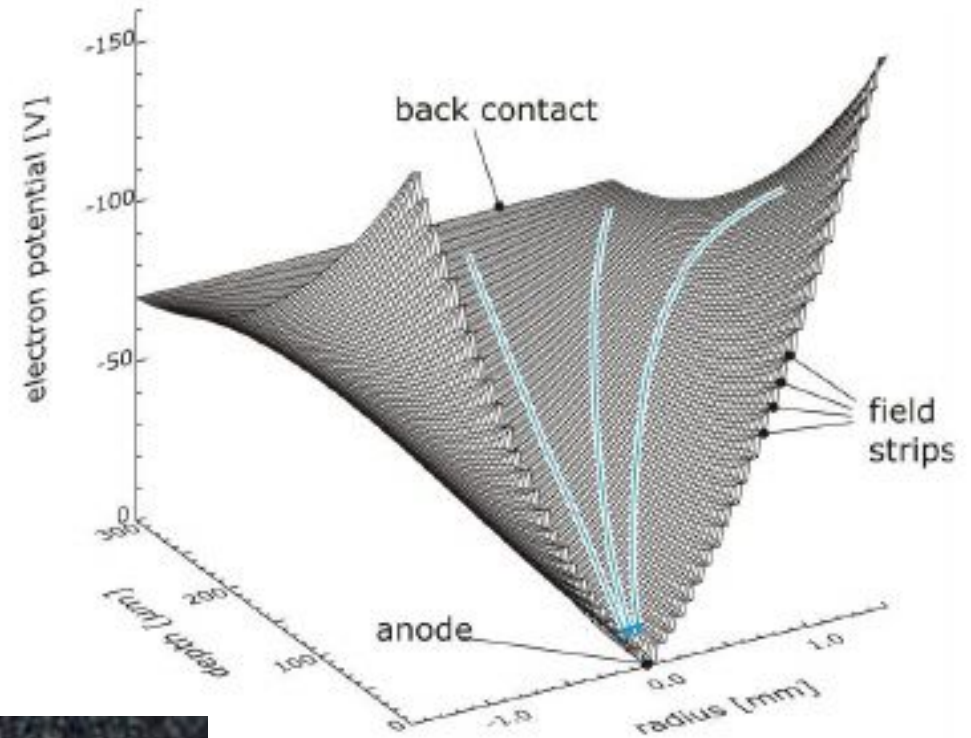
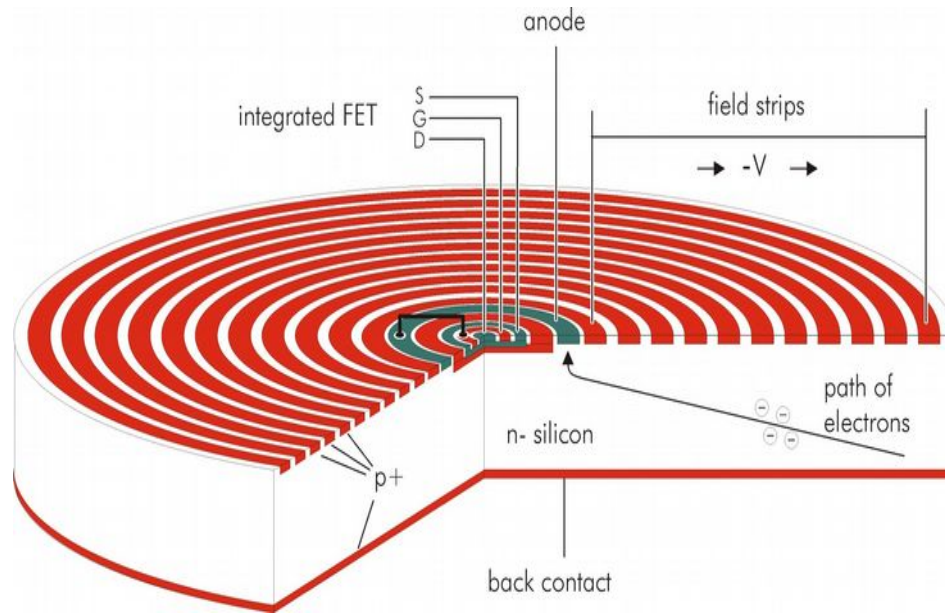


Le nombre de pixels totalisés peut être réduit si l'on en connaît la position de l'événement





Silicon drift detector





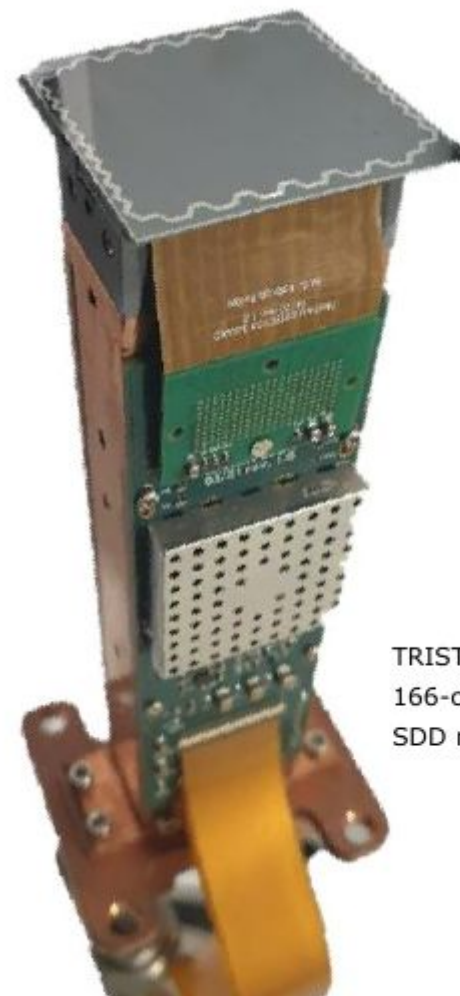
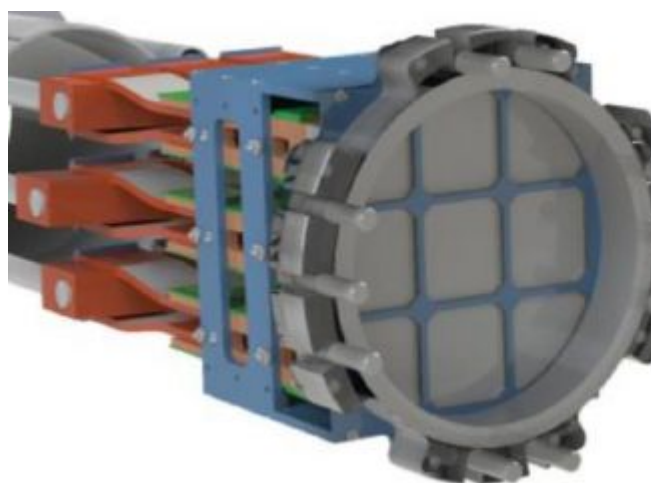
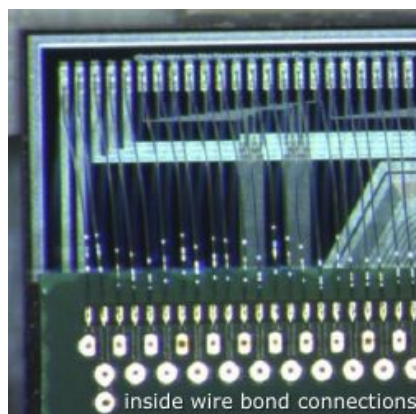
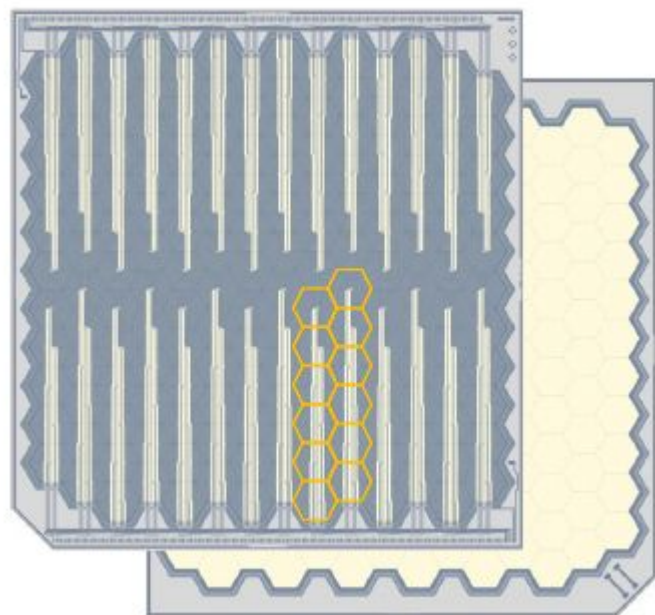
l'expérience TRISTAN à Karlsruhe Institut de Technologie



166 sdds individuels 3mm,
connectées au bord du chip.

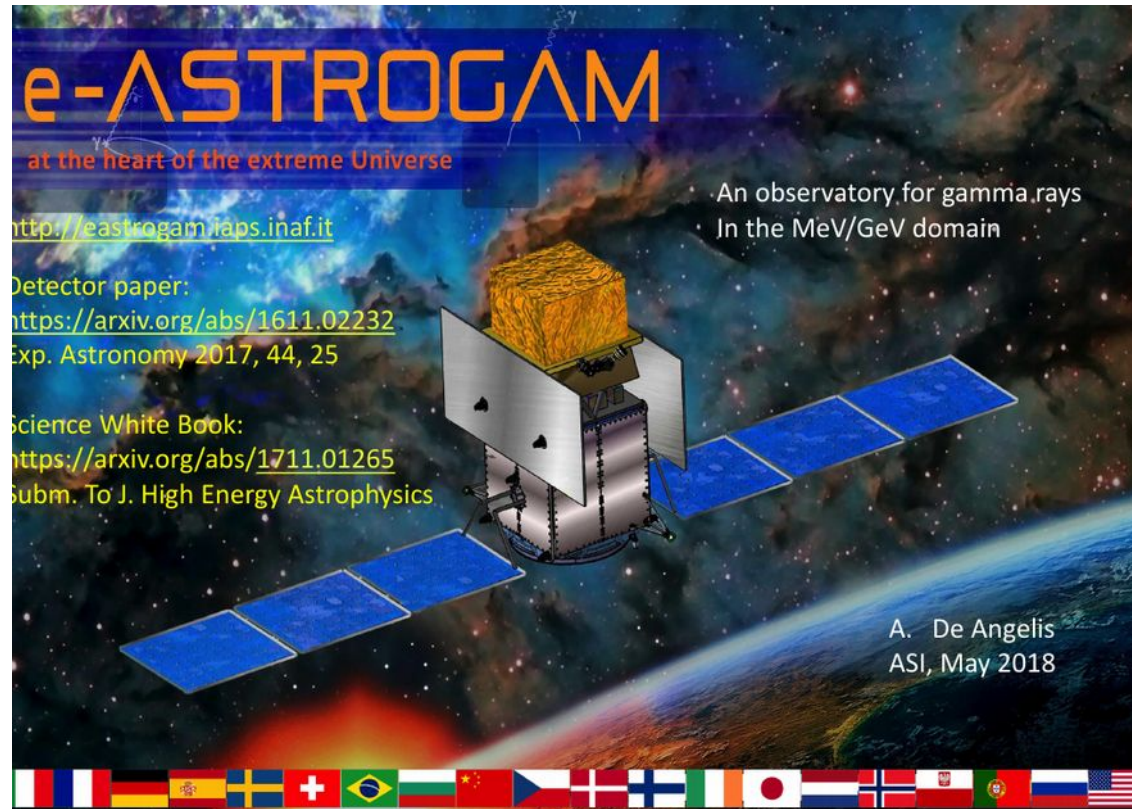
Tous canaux sont lu indépendant

Connections par fils



TRISTAN
166-cells
SDD module

phase 1 detector chamber



Le plan pour rayures (strips):

Longueur: ~ 30 cm

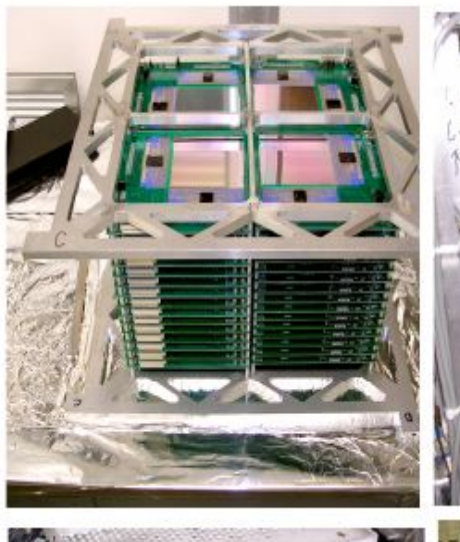
Largeur: ~ 1 mm



les Prototypes



TIGRE (2007) UCLA



Longuer: 20 cm

$> 3 \text{ pF / cm}$
 $> 10 \text{ nA / cm}^2$

p-side: $\sim 1500 \text{ e}^- \text{ ENC}$
N-side: $\sim 3000 \text{ e}^- \text{ ENC}$

ACT (2005) Naval Research Lab

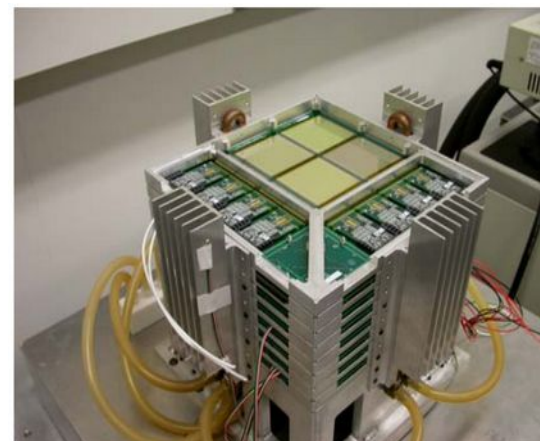
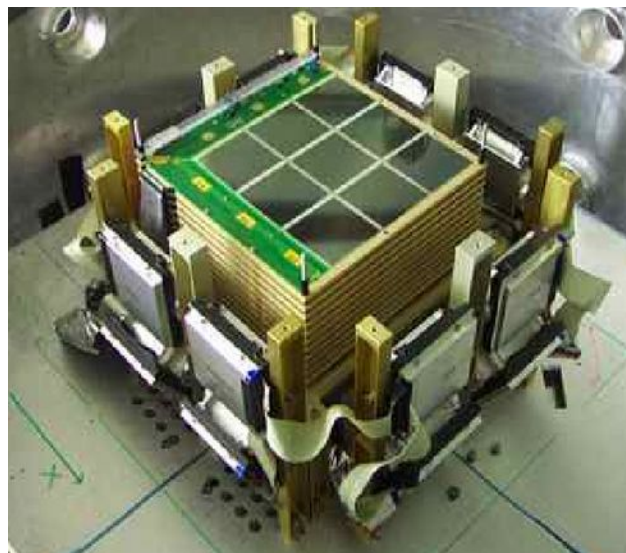


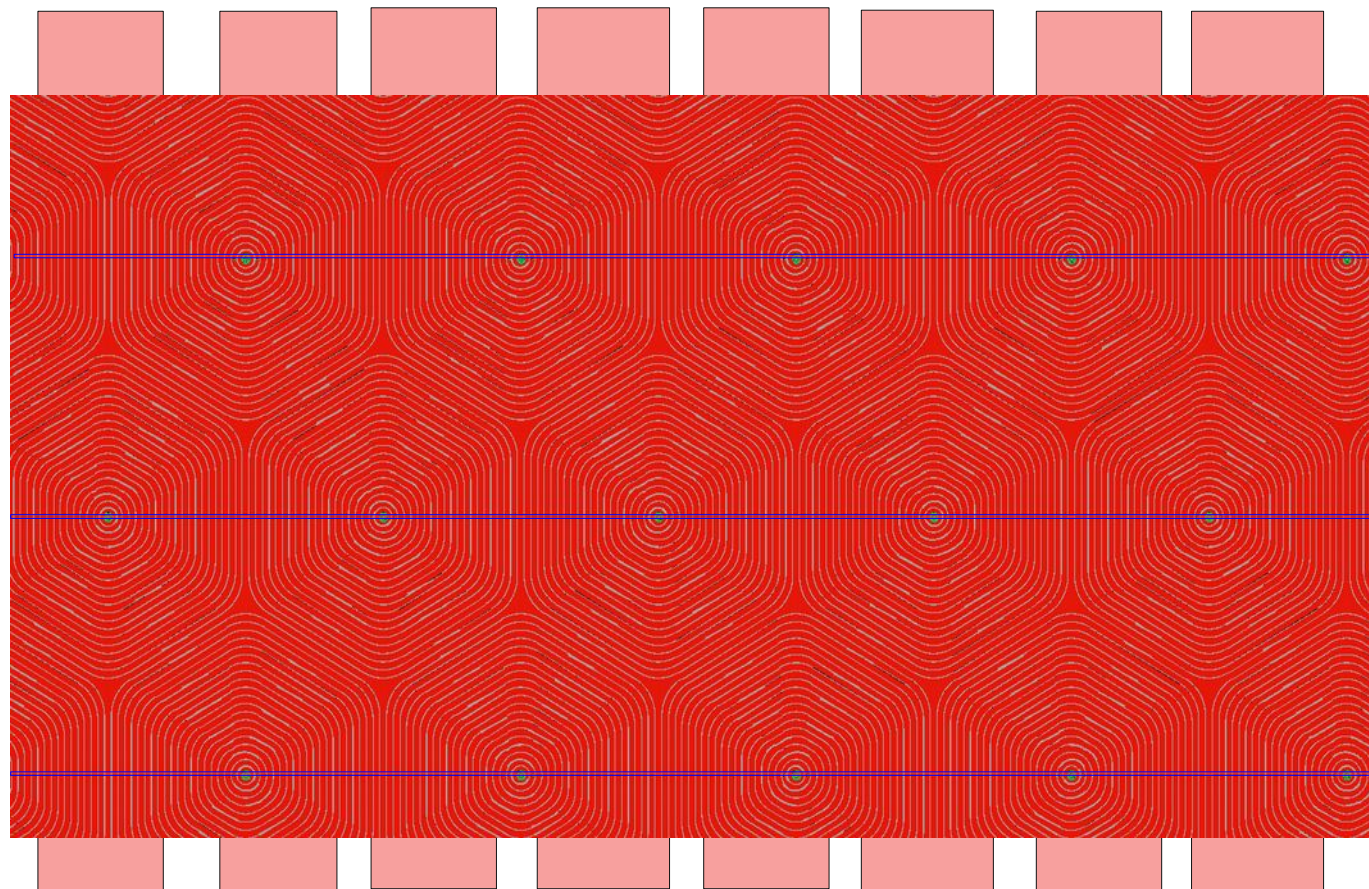
Fig. J3. An 8-layer Si detector prototype array, consisting of 32 2-mm thick detectors, of area $6.3 \text{ cm} \times 6.3 \text{ cm}$ each



MEGA (2004), MPE Garching



Est-ce que c'est raisonnable de combiner les rayures de face p avec des sdds a la face n ?



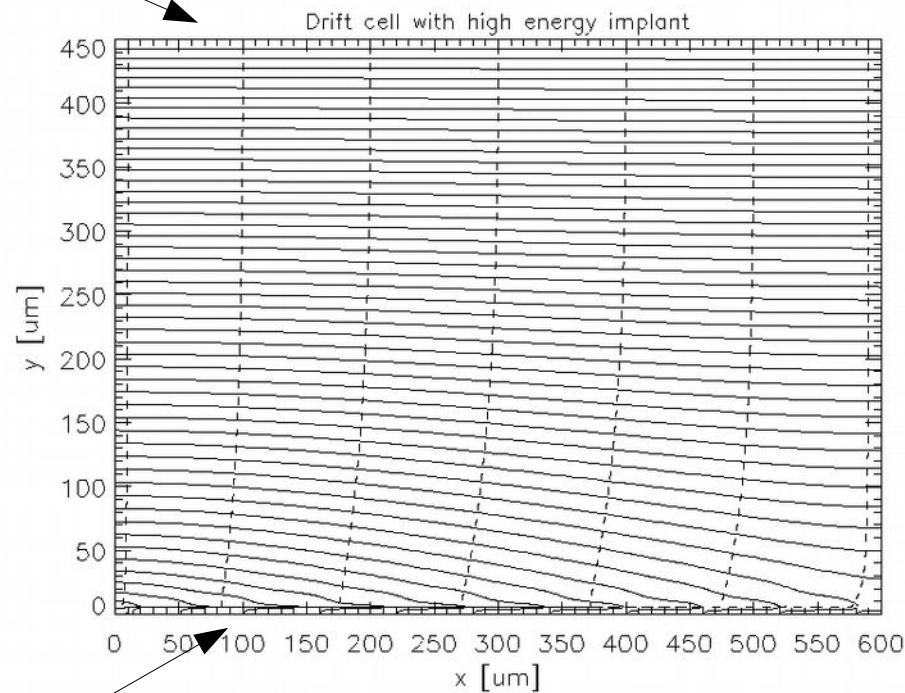
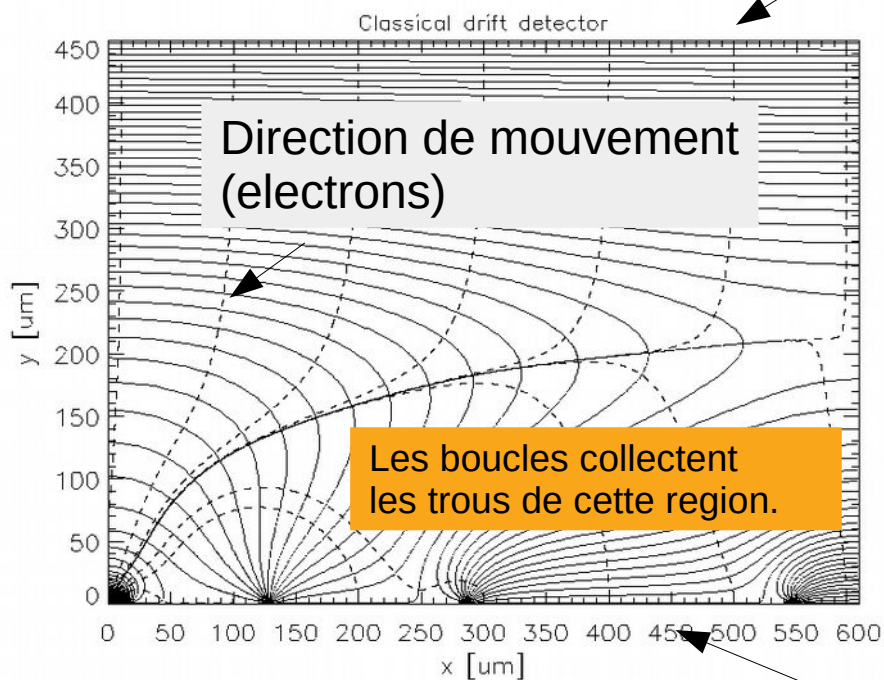


forme de champ électrique

Champ électrique
du sdd régulier

Champ électrique du sdd
avec une implantation haute énergie.

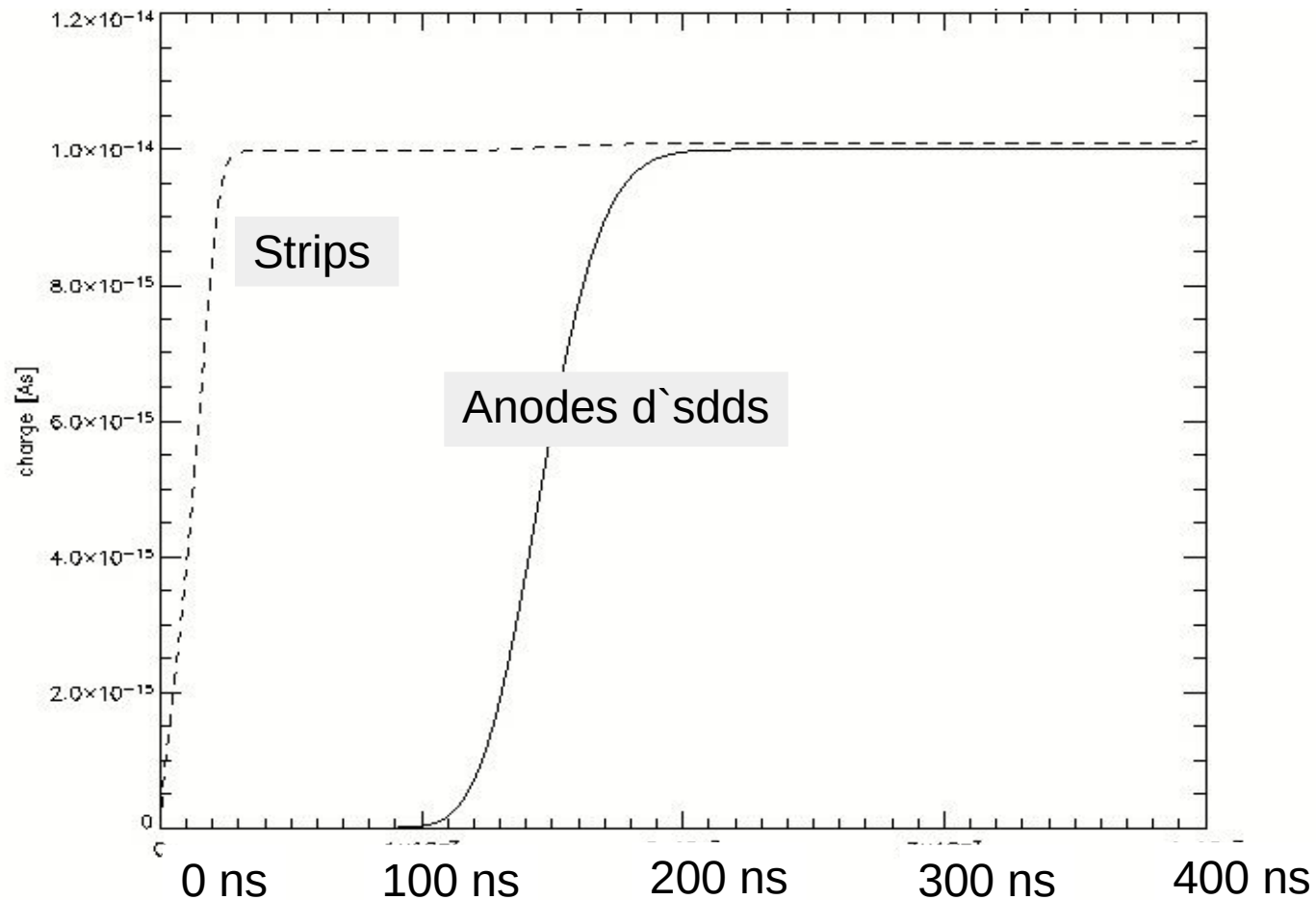
côté p: strips



côté n: sdd



Temps pour ramasser la charge dans les deux côtés



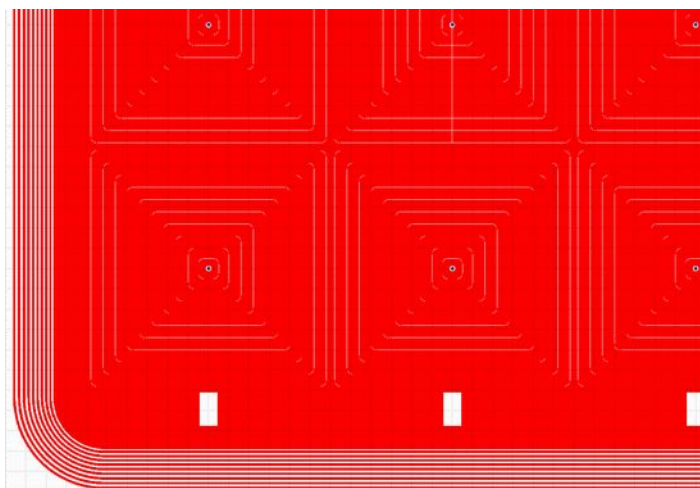
**Utiliser les signaux des strips comme trigger (plus vite) et pour la position x.
Utiliser les signaux de sdds pour la position y et l'énergie (capacité réduite).**



design et fabrication d'un prototype à HLL



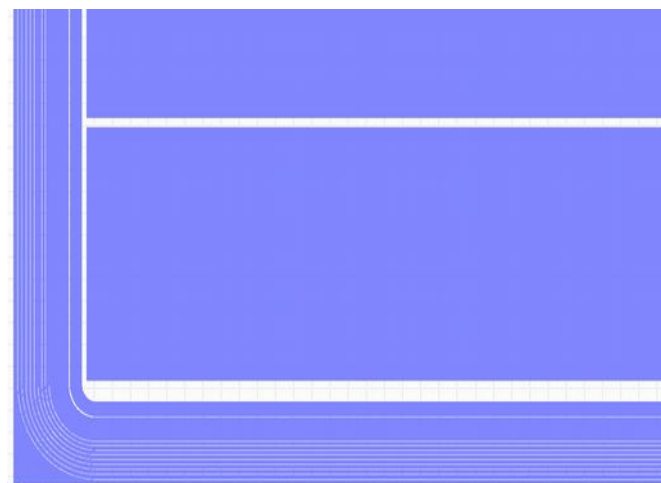
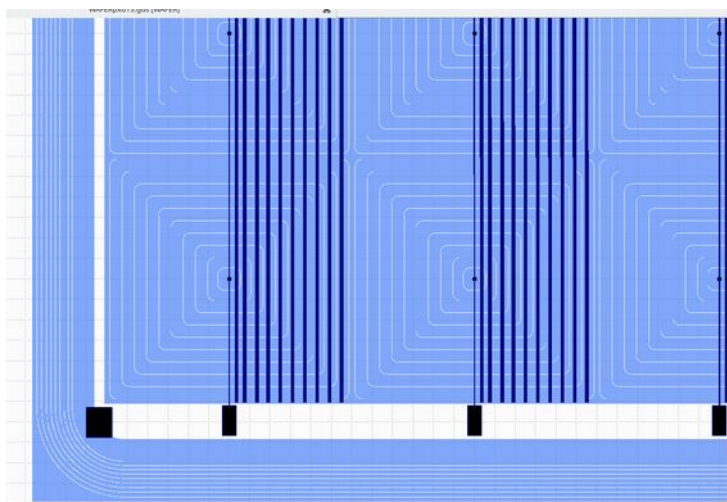
Face avant (sdd)
1,2mm



au verso (rayures)



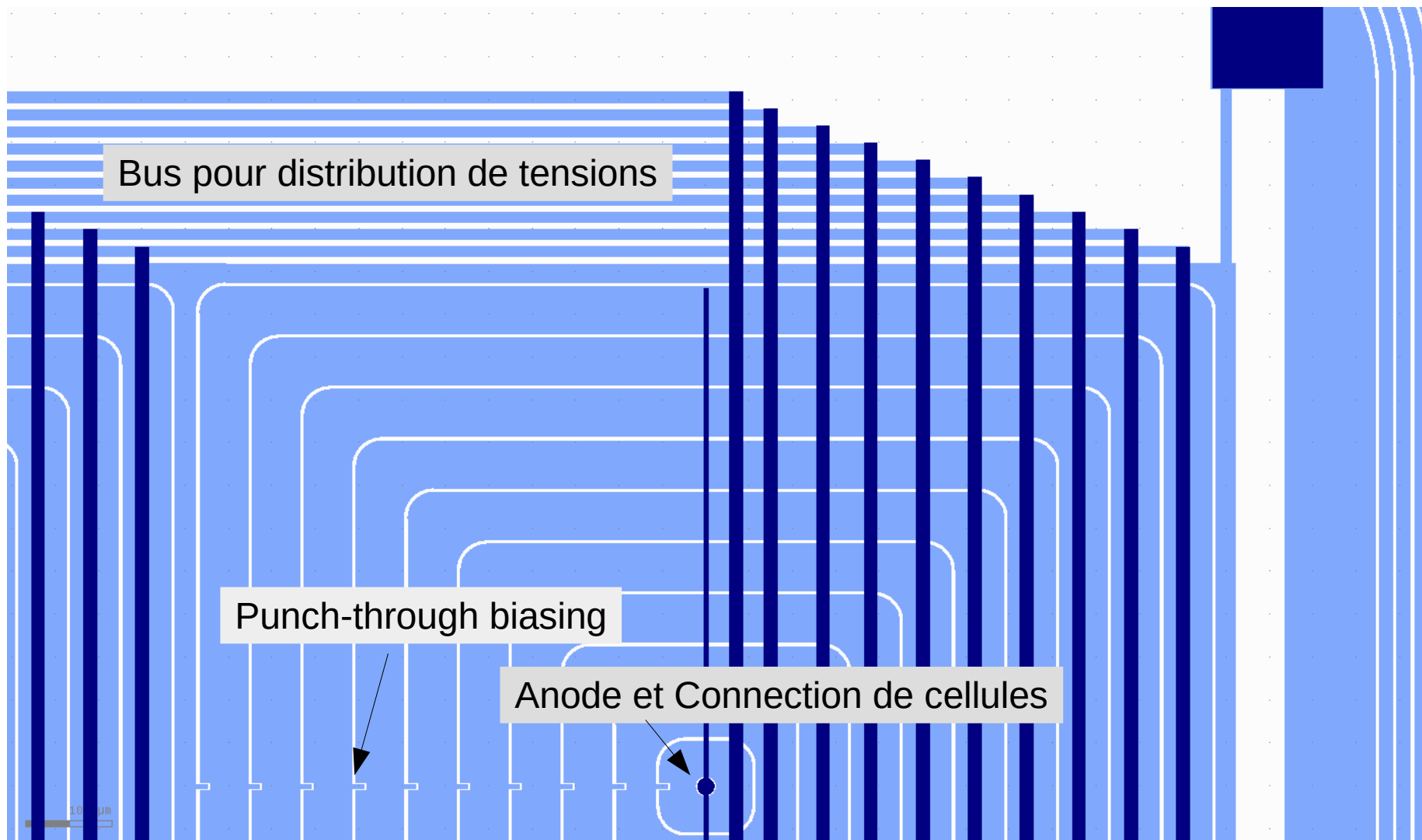
Implan-
tations
1,2mm



metal

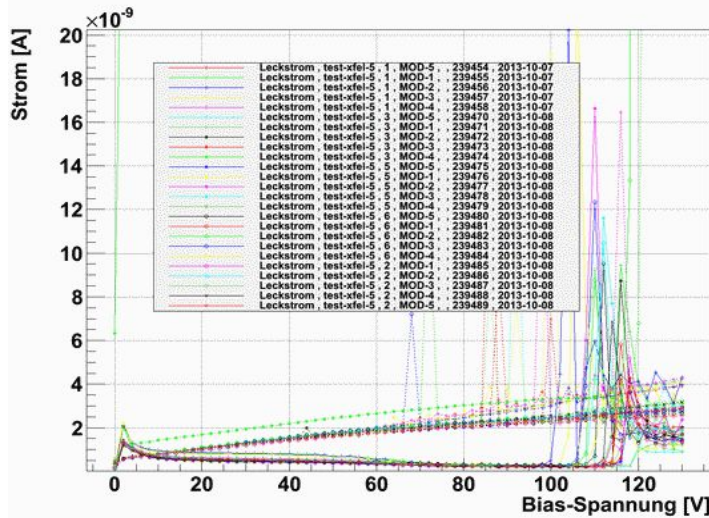


Connexion des cellules et prétension („Biasing“) des boucles





courant et capacité prognostiqué



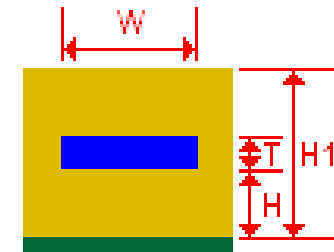
Courant: ~ **0.15 nA/cm²**

Production similaire mais sans segmentation de face arrière (sans rayures).

Capacité des anodes: **25 fF** → **0.2 pF / cm**
(sdds avec 1,2 mm diametre: 8 cellules /cm)

Capacité de lignes connectant les sdds:

Largeur W	Epaisseur H [μm]	C/cm [pF]
3 [μm]	0.55 ($\epsilon_{\text{Oxid}} = 4$)	3,3
3 [μm]	5 ($\epsilon_{\text{BCB}} = 3$)	0.55 pF/cm



nach <https://technick.net/tools/impedance-calculator/microstrip-embed/>



Fin

merci pour votre attention



Principe d'un imageur Compton

$$\cos \Phi = 1 - \frac{m_e c^2}{E_2} + \frac{m_e c^2}{E_1 + E_2}$$

