PICMIC: The First Results

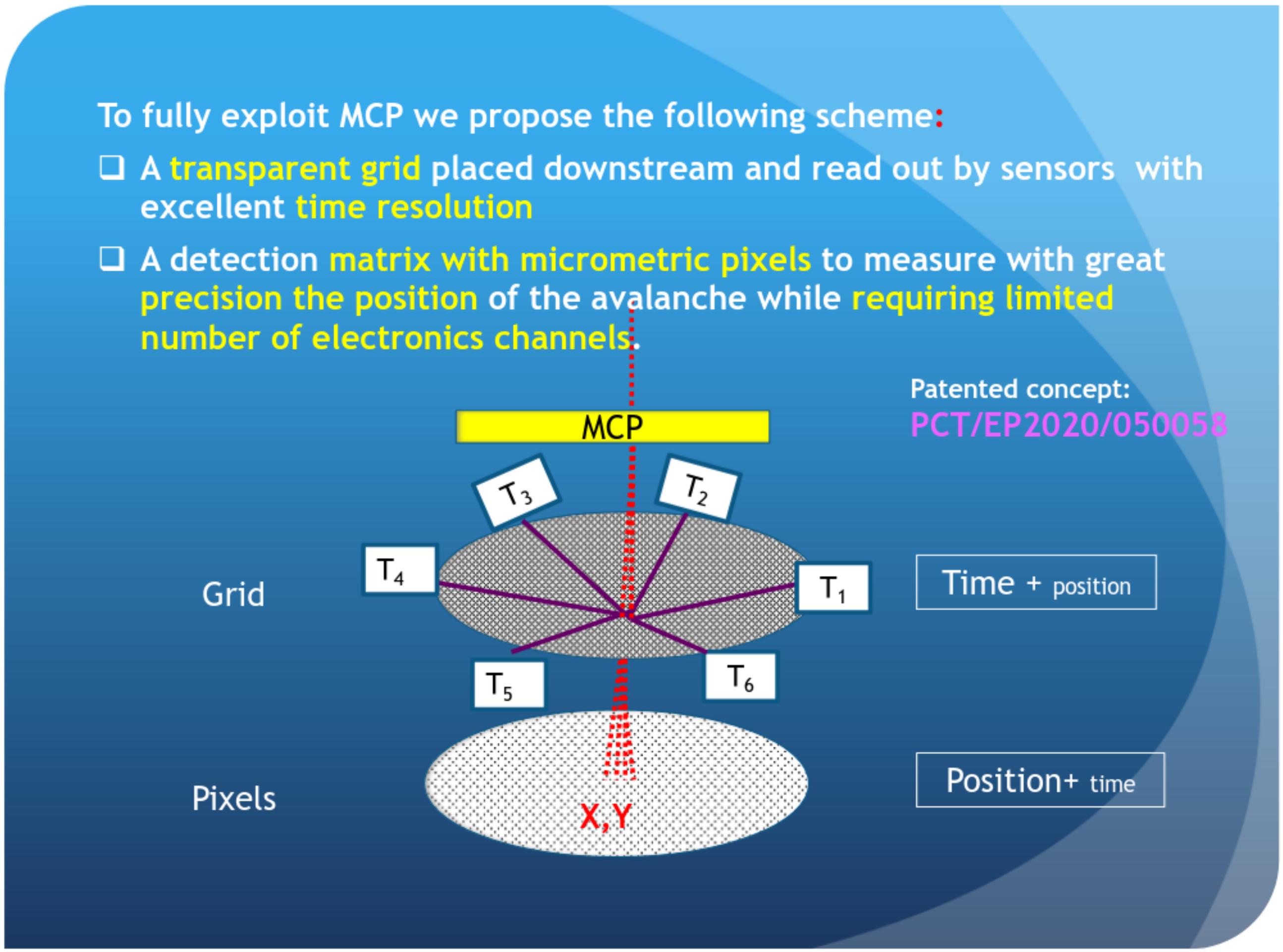
H. Abreu(1), E. Bechetoille(1,4), G. Bertolone(2,4), G. Claus(2), C. Colledani(2,4), C. Combaret(1), G. Doziere(2,4), C. Hu-Guo(2,4), I. Laktineh(1), H. Mathez(1,4), H. Pham(2,4), M. Specht(2), I. Valin(2,4), L. Zhang(3), Y.Zhao(2,4)

(1) IP2I, Institut de Physique des 2 infinis, CNRS/IN2P3
(2) IPHC, Institut Hubert Curien, CNRS/IN2P3
(3) SDU : Shandong University, China
(4) Mi2i: Microélectronique des deux infinis (CNRS/IN2P3)

Assemblée Générale du GDR DI2I
IP2I, 18-20 Juin 2025, Lyon

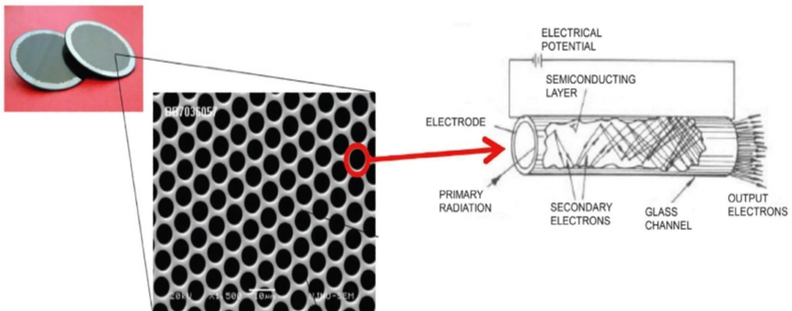
PICosencod sub**MIC**ron **detector:**

Imad’s presentation at https://t.ly/Iiw7G



PICosencod sub**MIC**ron **detector:**

MCP



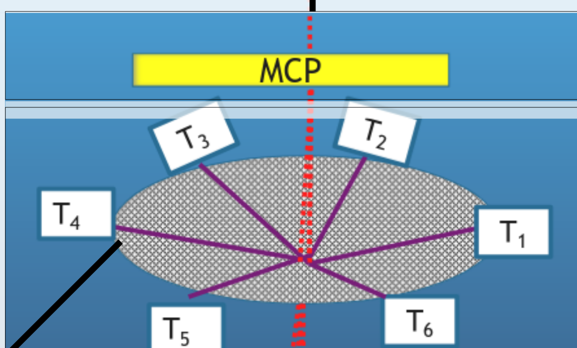
it allows the detection of charged particles but also neutral ones such as γ and neutrons when equipped with appropriate converters (photocathode)

L/D = 40-200

L is the plate thickness and **D** the tube diameter

D=3-25 µm

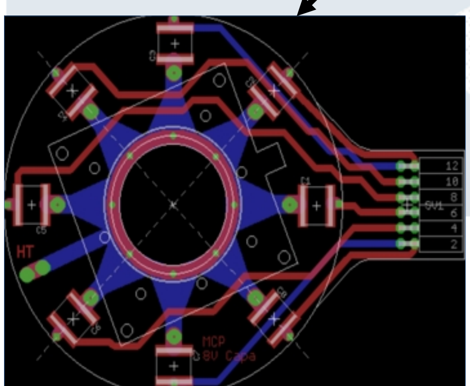
Gain/MCP ≈ 10000



TIME+position

8-point PCB for the time measurement.
PCB to be in contact with the grid

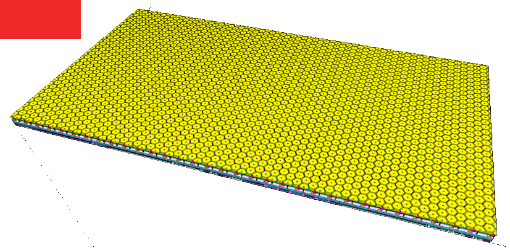
SAMPIC: WTDC ASIC allowing to reach ~3 ps time resolution



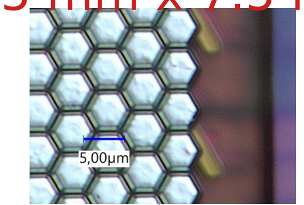
A modified version is used: mezzanine development for time and spatial syncro.

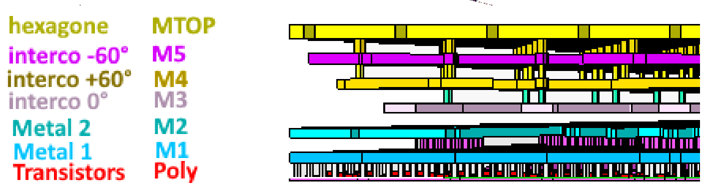
POSITION+time

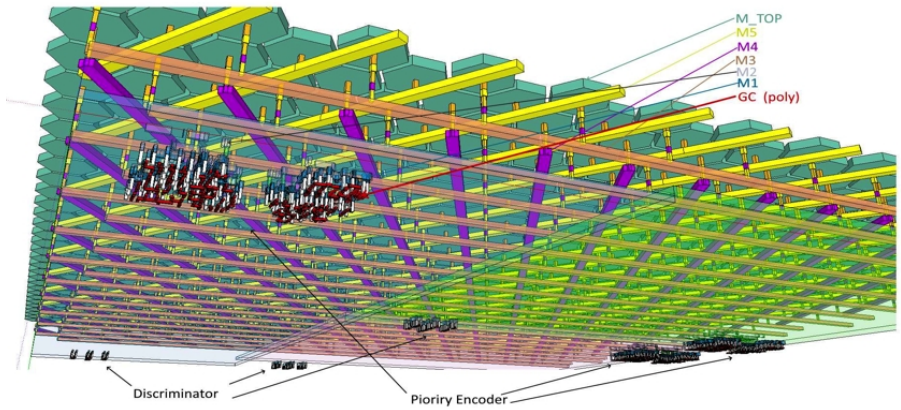
PICosencod sub**MIC**ron **detector:**



6.5 mm x 7.5 mm



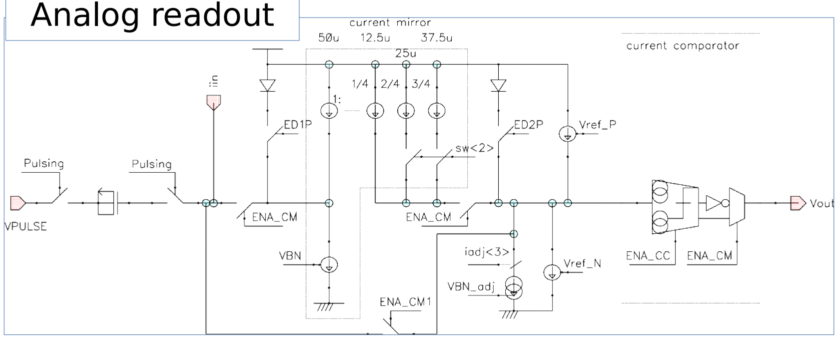




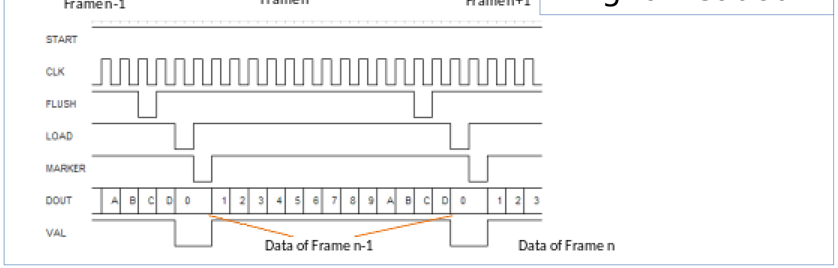
6 metal layer technology:

- 3xdirectionsx852 hexagon(**5µm**)-strip-lines, in TOP metal interconnector Metal-5-4-3
- [53,128] matrix of Analog+Digital comparator readout in M2 & M1, each line gets a comparator.

Analog readout



Digital readout



Very front-end:

- Current mirror + current comparator
- Current reference: global 8-bit tuning DAC + 3-bit local
- protection diodes

i2c Slow control :

- global registers + each readout-cell locally
- Column readout by priority encoder

Parallel readout :

- 13-bit data (touched pixel address) + Marker
- 40MHz // readout speed
- 16 sample by frame : 16* 25ns => 400ns frame

Pedestal threshold calibrations (1/2)

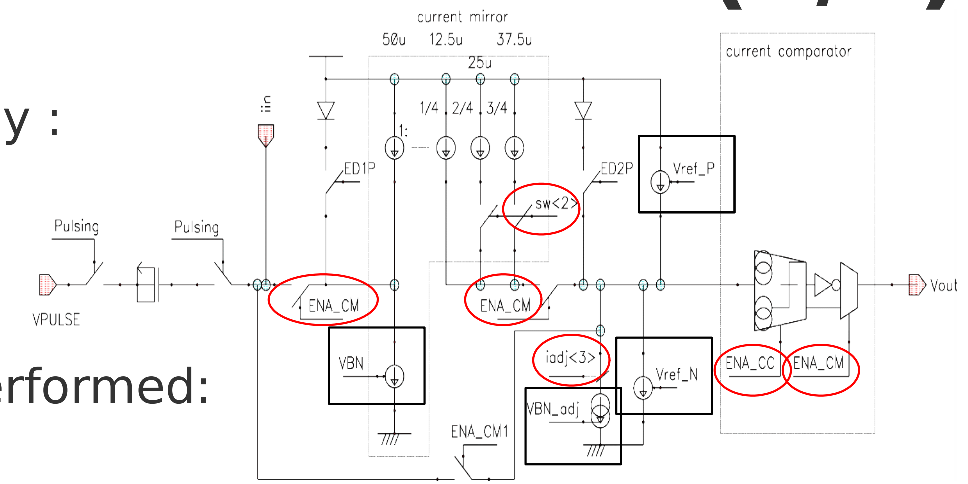
[Protocol]

1) Freeze a set of **DAC**(Global) values driven by :
   - small dispersion between s-Curves
   - bigger number of sCurves in a given space of phase vs VRefN(quite sensitive)

2) Then, additional scan in **local** values are performed:
   - iadj<3bits>, sw<2bits>, EN_CM, EN_CC.

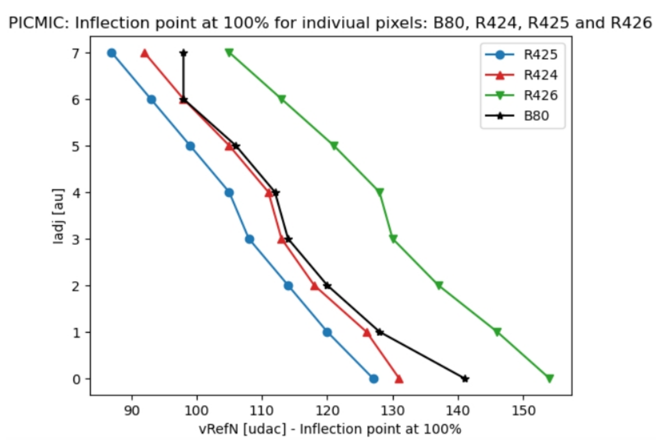
3) To determine value @50% inflection point.

4) To select the closest sCurves@50% to VRefN

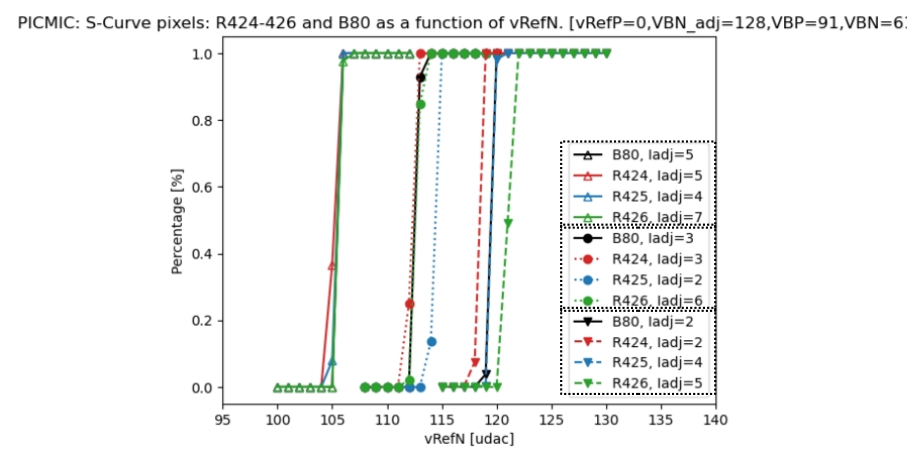


PICMIC Very Front-End synoptic(Analog part)

The first tries were performed choosing a few channels (among the 2556 available):



2D scan [**iadj** vs VRefN] results following steps1-3 of the protocol



Matched sCurves(VRefN) for sets of values in **iadj**

Pedestal threshold calibrations (2/2)

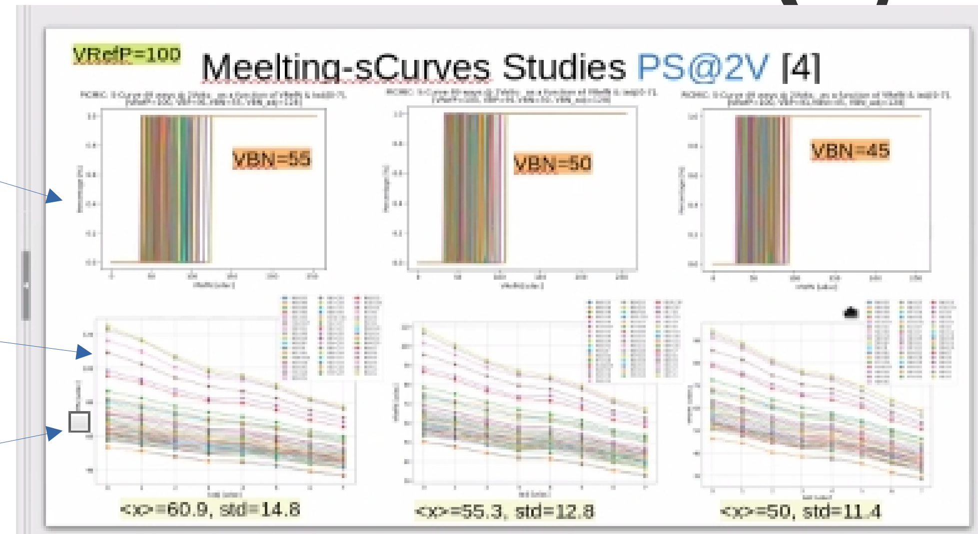
[Protocol]

1) Freeze a set of **DAC**(Global) values driven by :
   - small dispersion between s-Curves
   - bigger number of sCurves in a given space of phase vs VRefN(quite sensitive)
     -- VRefP=50, VBP=90, VNB=45, VBN_adj=128

2) Then, additional scan in **local** values are performed:
   - iadj<3bits>, sw<2bits>, EN_CM, EN_CC.

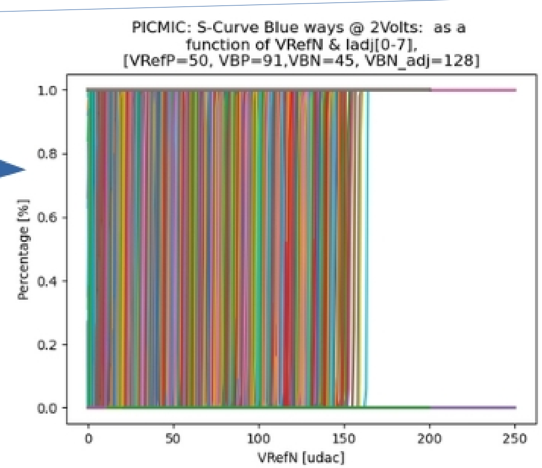
3) To determine value @50% inflection point.

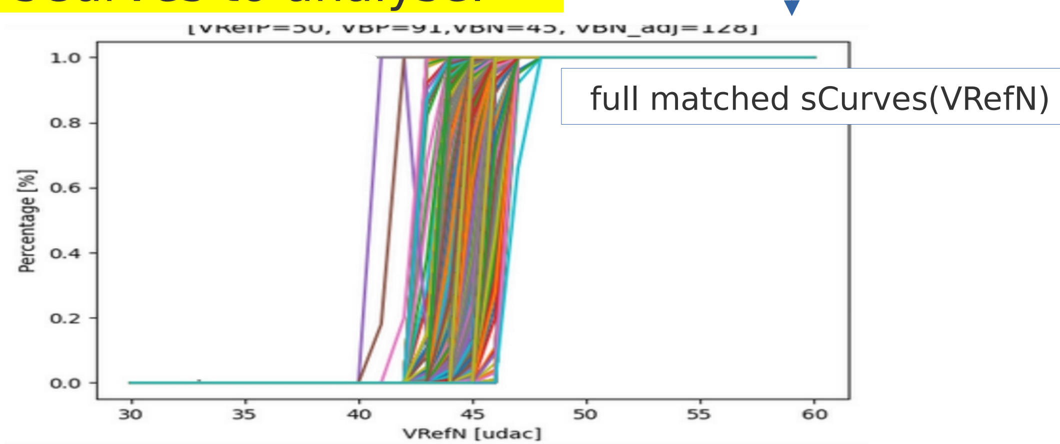
4) To select the closest sCurves@50% to VRefN.



<u>The software's interface of the test bench modified to allow up to 5-Dimensional scans.</u>

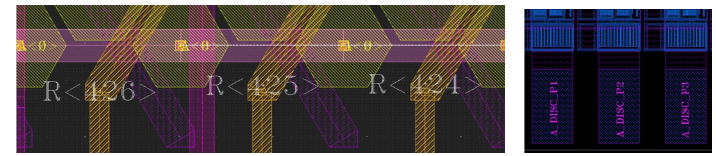
Full calibration of 2556 channels. **Global** fixed, varying **local**:
32 configurations per channel: ~81800 sCurves to analyse.



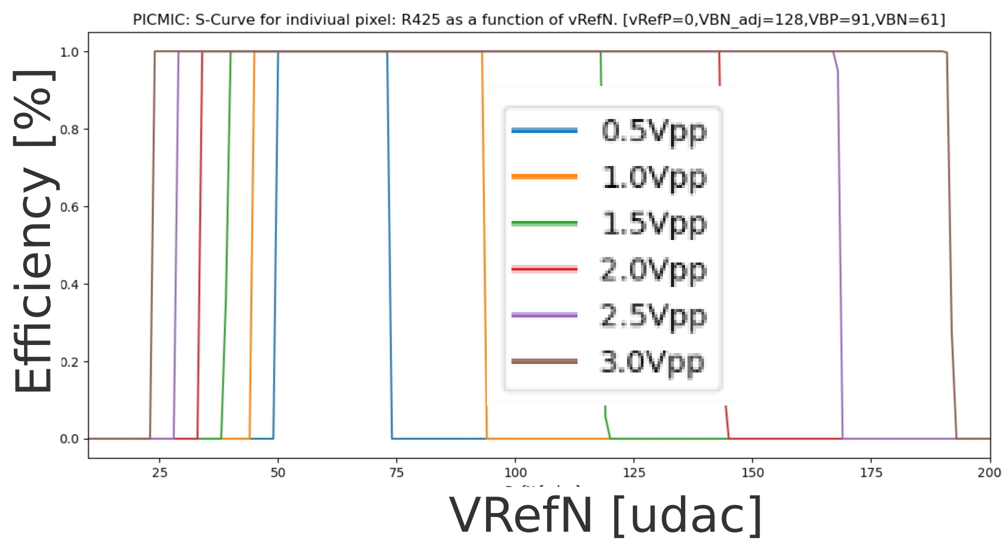


*Excluded 38 Yellow channels (Metal 3), noisy due to coupling between memory flush signal in Metal 2

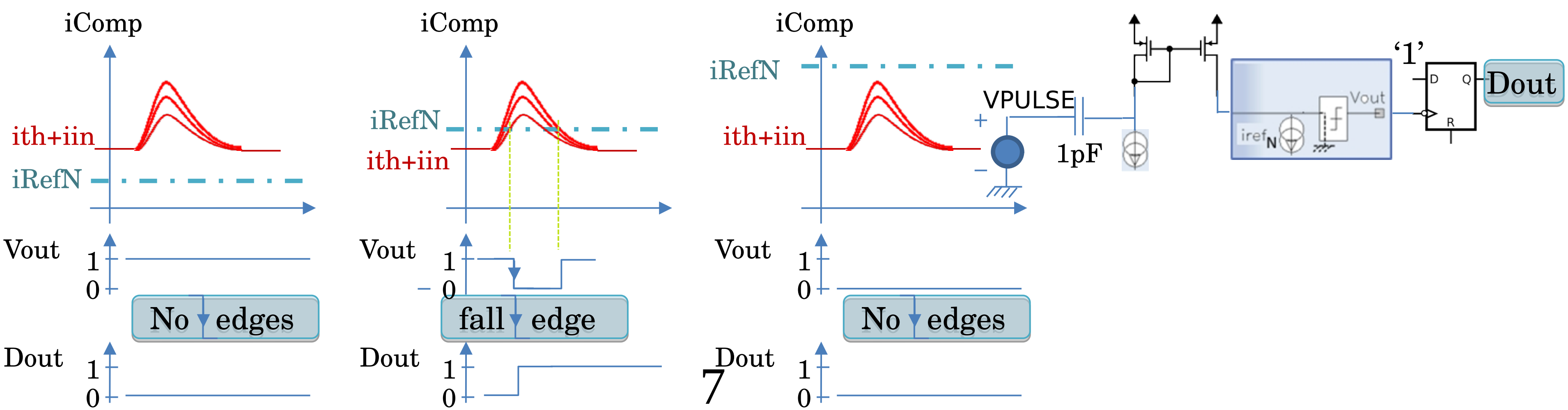
Injections Studies (1/2)



PICMIC allows external signal injection trough the (PAD):
- **R424**[R68,C28],**R425**[R103,C35] and **R426**[R6,C15].
- * it also allows to excite whole columns in the channel matrix (no shown in above layouts).

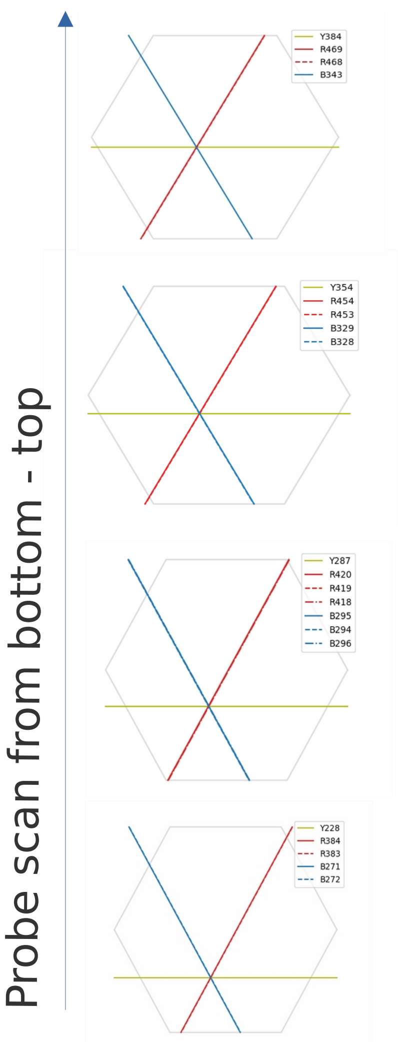


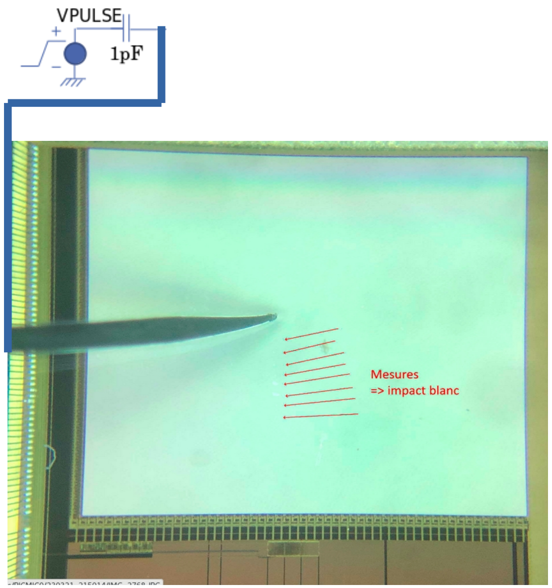
- Voltage injection through external 1pF, then scan of the threshold of Current Comparator.
- Below the current threshold, the falling edge sensitive does not trig.
- The signal is recorded on falling edge, so above a certain value of iRefN added to threshold current, the comparator does not trig anymore-→ chapeau!

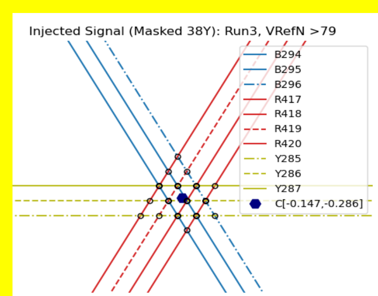


Injections Studies (Probes) (2/2)

Having the full pedestal thresholds under control (PICMIC calibrated). We proceeded to accomplish an important mainstone. Direct inject on the surface.

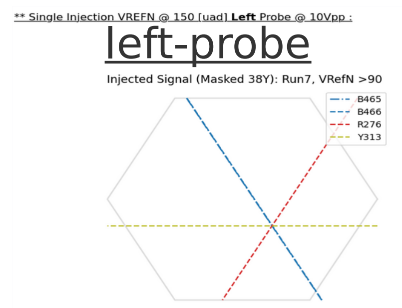


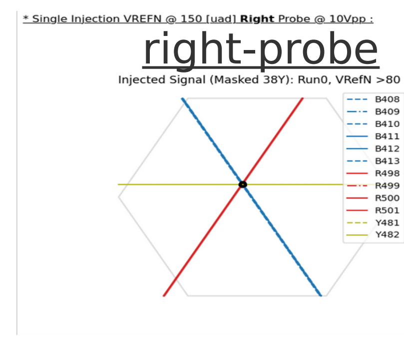


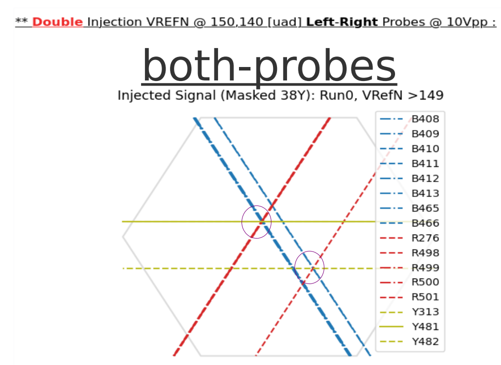


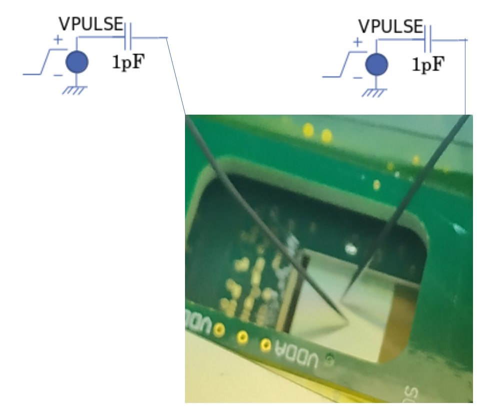
Clustering and centroid estimation

Two probes injection

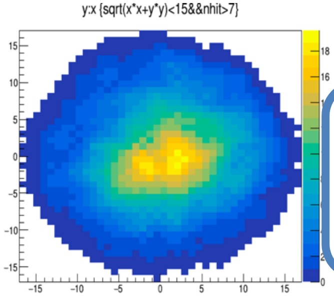








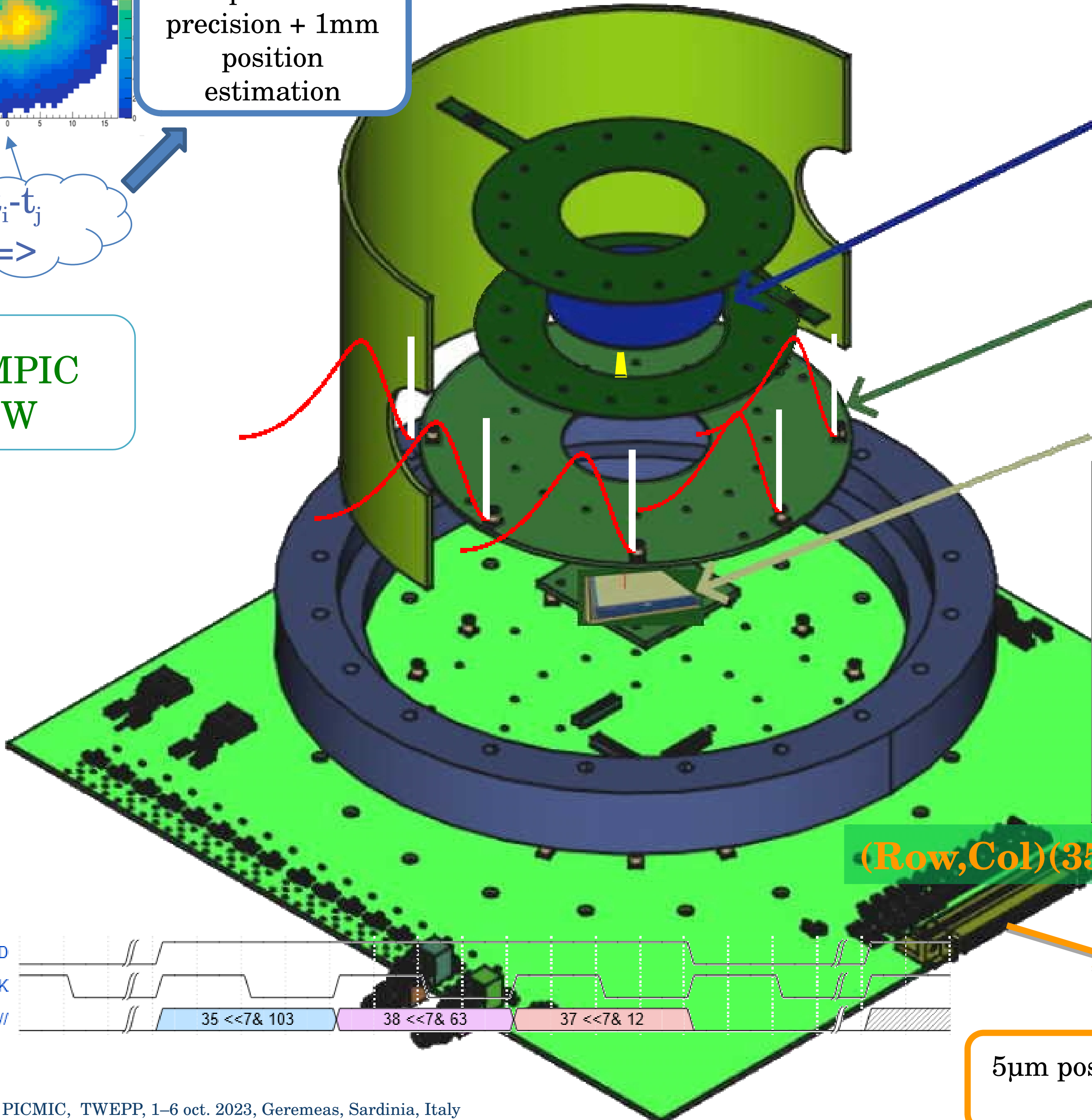
Proof-of-concept Demonstrator

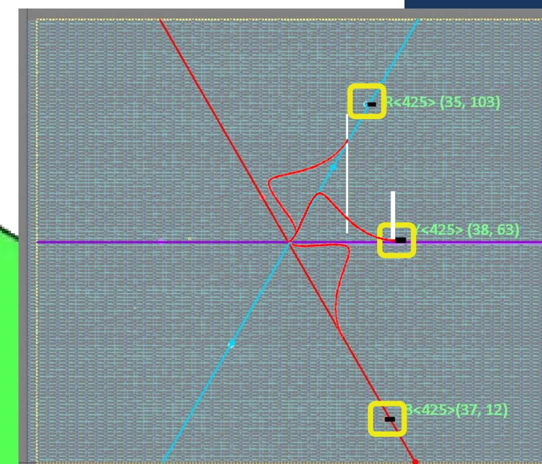


3ps Time precision + 1mm position estimation

t_i-t_j
=>

SAMPIC HW





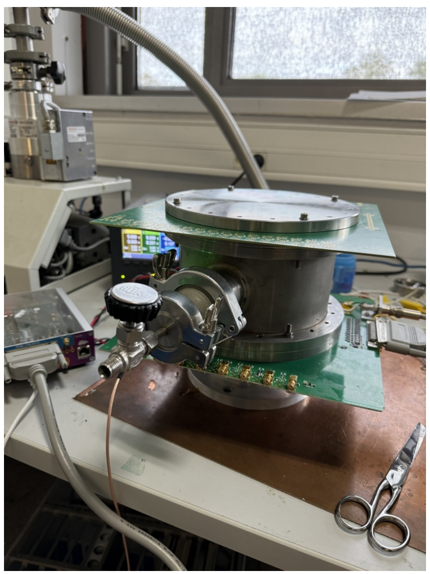
(Row,Col)(35,103)(38,63)(37,12)

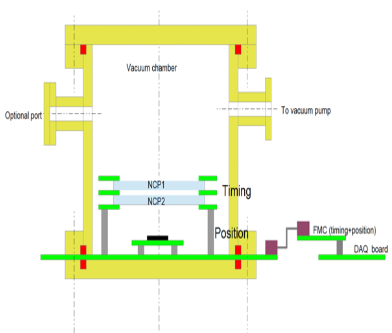
SAMPIC FirmWare

5μm position, in 400ns frame resolution

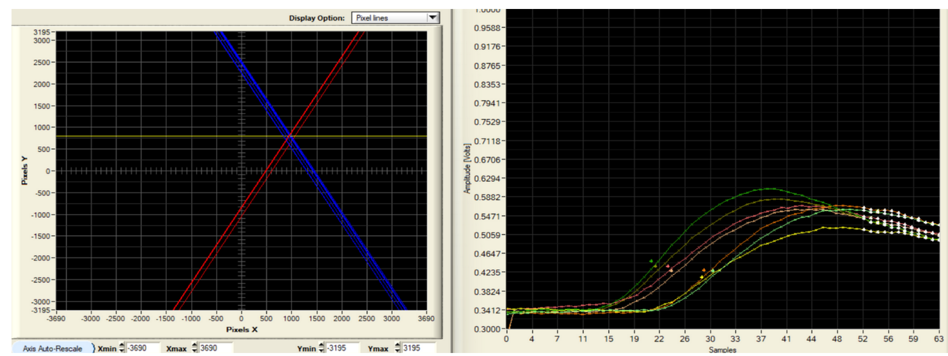
Proof-of-concept demonstrator

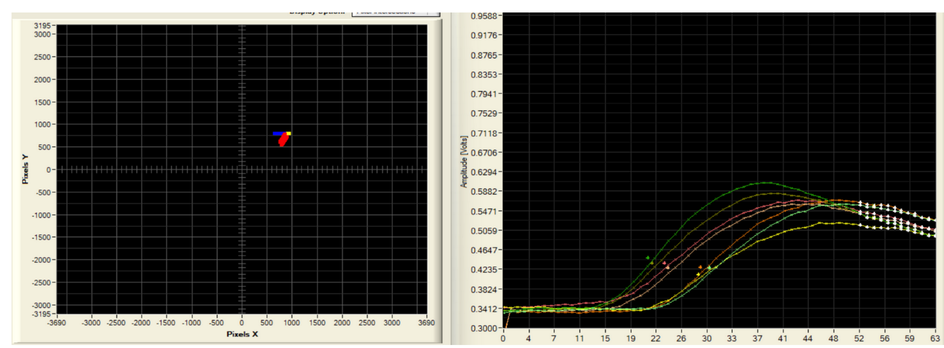
- SAMPIC WTDC integrated with the PICMIC0.
- New Calibration (pedestal threshold) in-situ, to avoid potential noise from the setup.





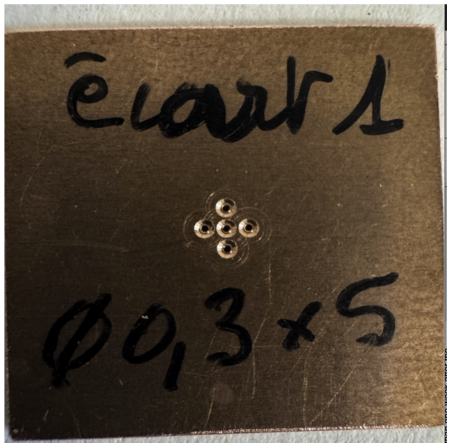
- **concept validated!.**
- Work in progress to reduce channels dispersion. Fine tune at the calibration level.
- Developing coincidence protocols (SAMPIC+PICMIC0)
- Looking forward to move and test with beams.

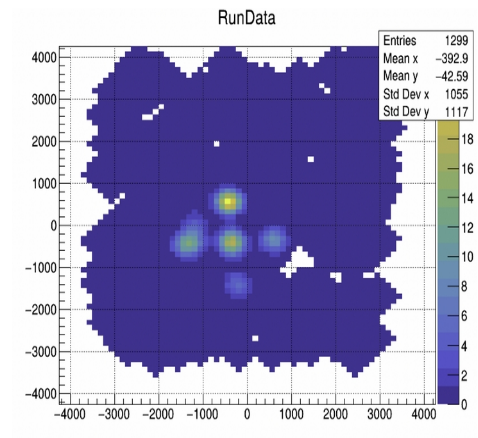


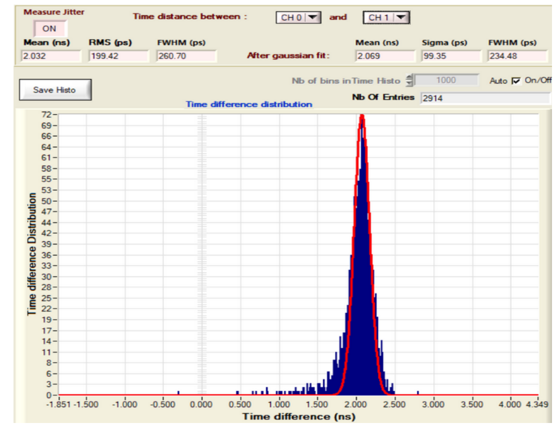


Proof-of-concept demonstrator

First demonstrator results:







- Spatial dispersion < 70 µm

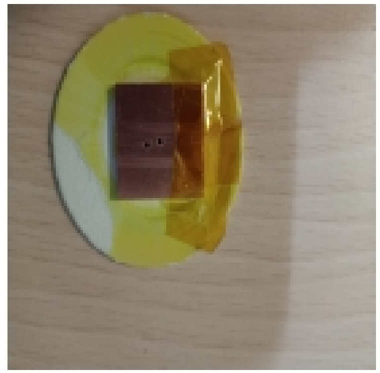
-Next version of pixels sensor has been submitted and we expect to reach 10 µm

σ (T_i -T_j) is better than 100 ps

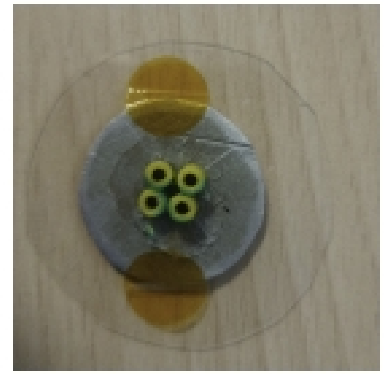
σ_{abs} is around 25-30 ps

- Even with our first version we have better results than Timepix4

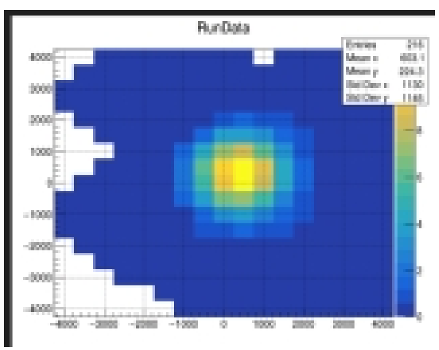
Proof-of-concept demonstrator

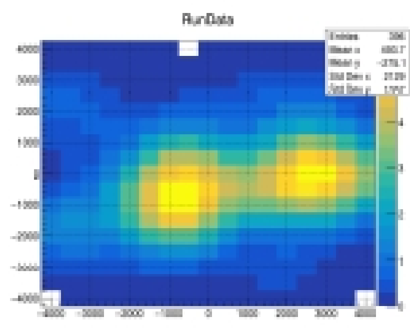


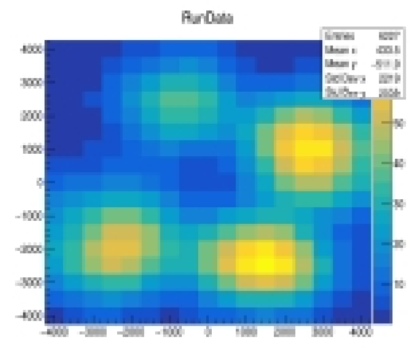
1mm holes

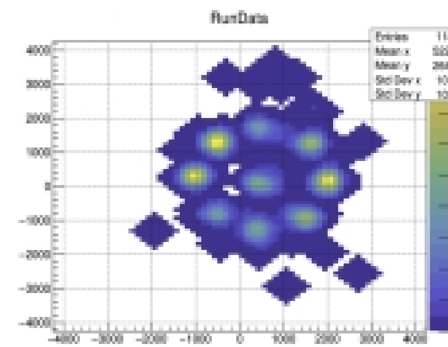


2mm holes









Future plans:

- Hit rate improvement from 40Mhz to 160MHz

- **Sensor size to increase x 4**

- Hexagon pitch from 5um to 1.25um, no for next version

- migrated in a smaller tech node like 65nm or less (with more metal layers)

- narrow electron shower to keep PICMIC0 target resolution → Going beyond of MCP

- Idrogen (high rate readout).

- Small feature corrections from PICMIC0

Going beyond to MCP to NCP

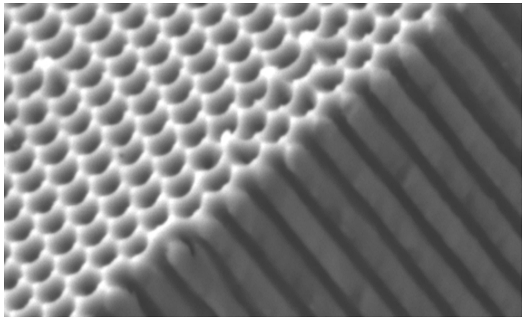
A new kind of MCP that we call NanoChannel Plate (NCP) is being developed. It aims at producing structures with nanoholes that could be coated with emissive and resistive materials to achieve unprecedented performances.

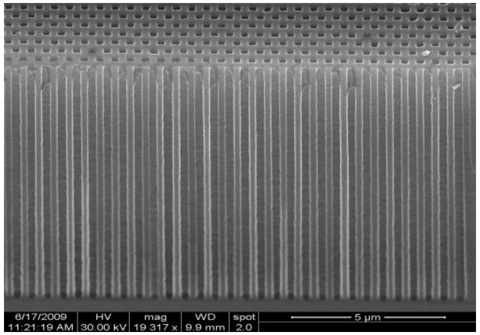
Three technologies are followed :

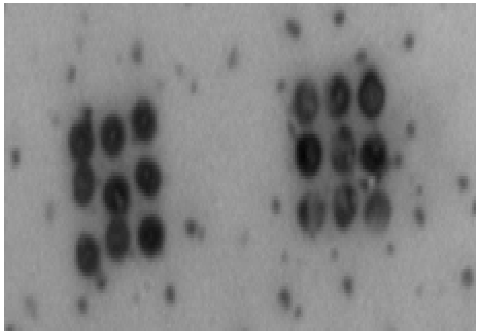
- Nanopores → NCP? We need to coat the holes’ walls with resistive and emissive material:

  - Anodized Aluminium Oxide AAO * (IP2I-IMP) – testing!
  - Silicon electrochemical etching (IP2I-INL)

- Femto-laser digging (IP2I-LabHC)







* A try with a good polymer was also tested.

Nano-Channel Plates (NCP)

- **Simulations (Lili LI)**

DOI:10.1103/PhysRevSTAB.5.124404
Durham-Pivi; Probabilistic model for the simulation of secondary electron emission

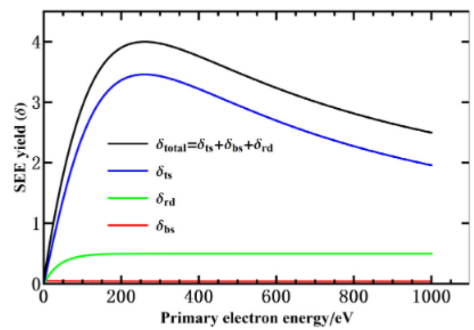
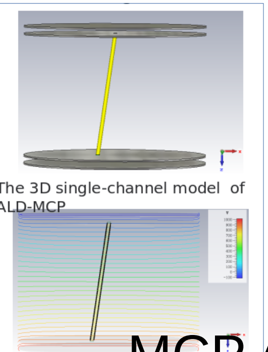


Fig. 4. SEE yield as a function of primary electron energy over the range of 0 eV < E < 1000 eV at normal incidence.

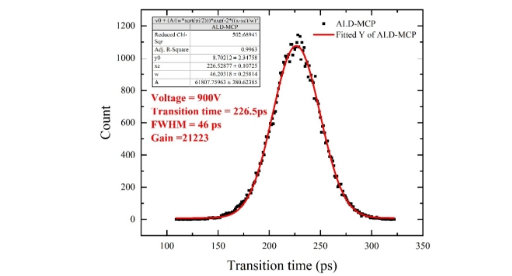
<u>Total Electron Yield Al2O3</u>



The 3D single-channel model of ALD-MCP

Parameter	Value
L	400
D	10
L/D	40
Bias angle	8 degrees
electrode penetration depth	5
electrode material	nichrome
secondary electron emission material	Aluminum-SEE
Voltage	900V

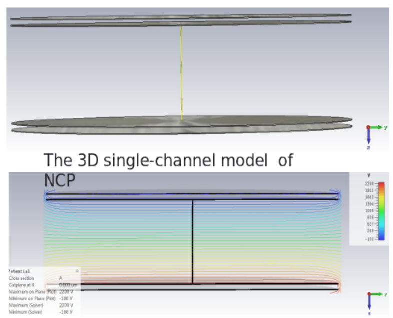
<u>MCP ALD Al2O3</u>



The transit time distribution graph of the emitted electrons

The result:

Transition time = 226.5ps, FWHM = 46 ps, Gain =63669/3=21223



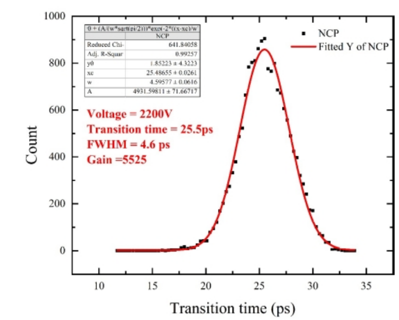
The 3D single-channel model of NCP

The spatial distribution of equipotential lines in an electric field

Parameter	Value
L	50
D	400nm
L/D	120
Bias angle	0 degrees
electrode penetration depth	4
electrode material	nichrome
secondary electron emission material	Aluminum-SEE
Voltage	2200V

<u>NCP ALD Al2O3</u>

The secondary electron emission coefficient from the ALD-MCP simulation are used.



The result:

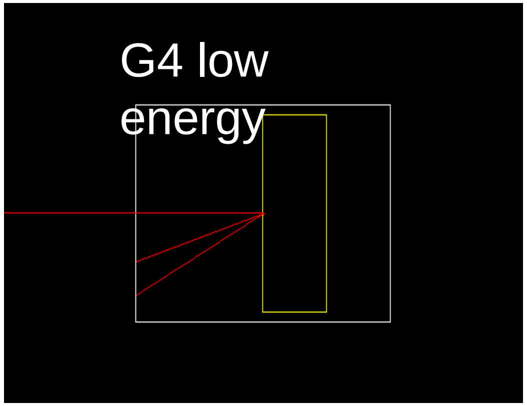
Transition time = 25.5ps, FWHM = 4.6 ps, Gain =16,575/3=5525

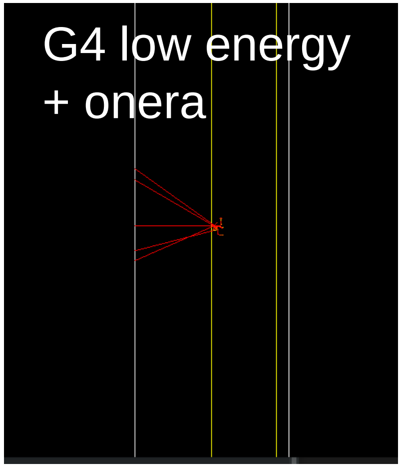
- Time and spatial resolutions are expected to be 10 times better.
- NCP has very good time characteristics. When the voltage is higher, the FWHM may reach 1ps and the gain can be higher.
- The space charge effect is considered in the simulation..
- a couple of more configurations have been tested (Voltage, L/D, etc), quite time consuming.

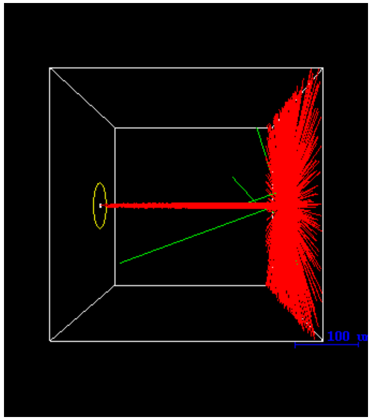
Nano-Channel Plates (NCP)

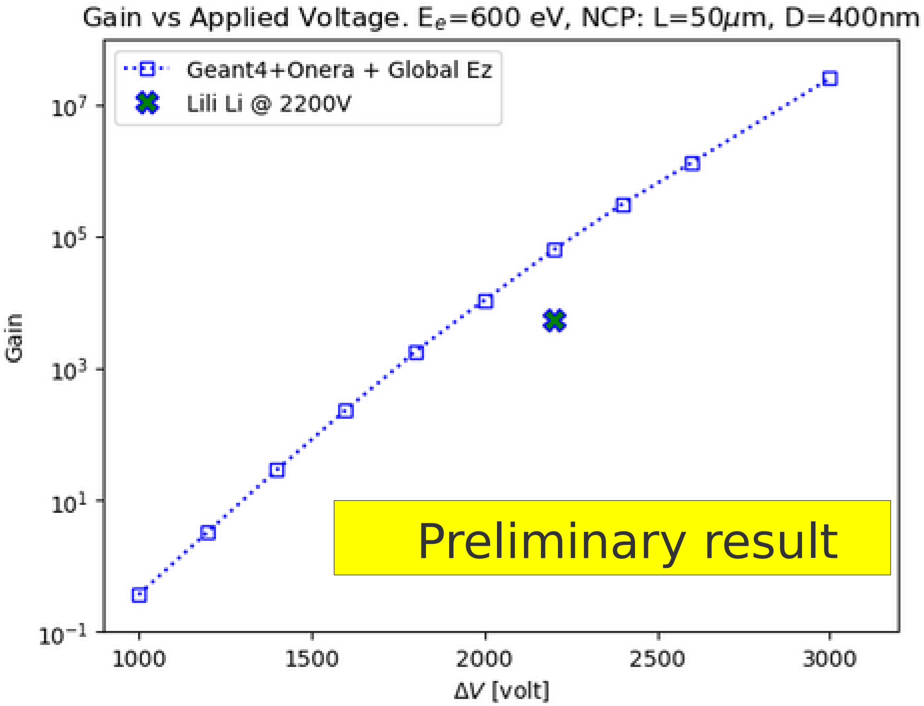
- **Simulations (IP2I-ONERA)**

We are able to get similar Lili LI NCP Gain results by using GEANT4+Onera microelectronics (an optimization of the stopping power for low energy particles + work function, and for certain materials when needed phonon interactions in order to simulate properly the SEY for several materials)







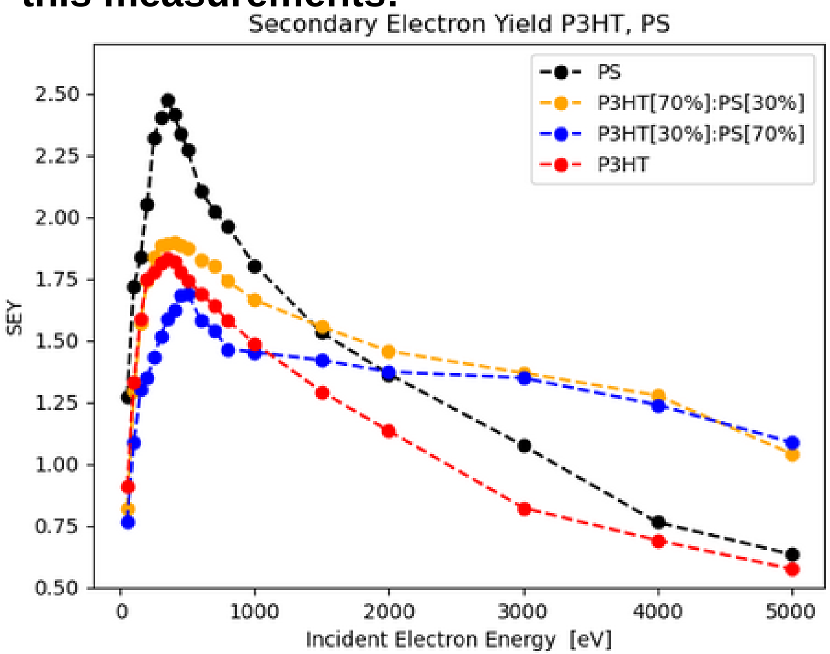


Gain vs applied Voltage for a NCP, L=50μm, D=400nm

Going beyond to MCP to NCP

In collaboration with the **IMP-Lyon**, we identified a good polymer (a semi-conductor) and the preliminary result are very encouraging, still needs performance studies at vacuum and under radiation conditions.

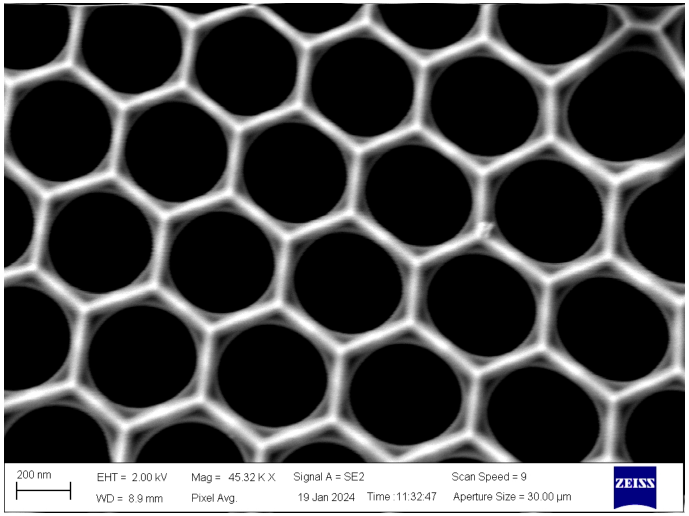
Thanks to Gaël SATTONAY and their colleagues at the IJCLab to make possible this measurements!



- A new material (emissive layer) is being studied, backup solution for NCP walls (P3HT+ polystyrene) certainly with a SEY of 2 but still greater than 1.

-At present moment, we are testing a NCP with an emissive layer=P3HT(30%) +PS(70%)+ dopped with Alumina powder. **– <u>Quite promising</u>**

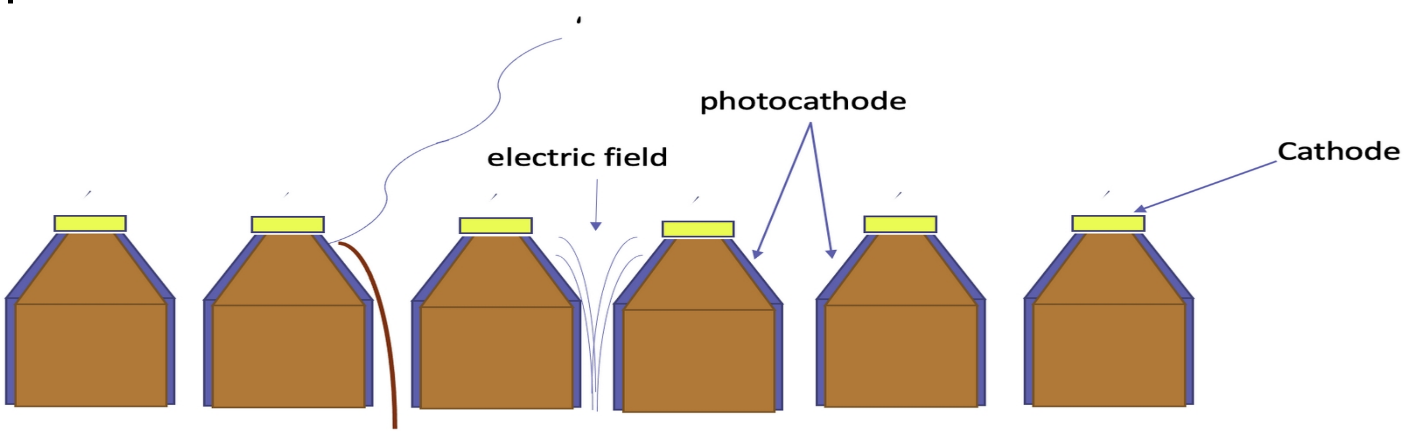
NCP, L=50μm, D=400nm

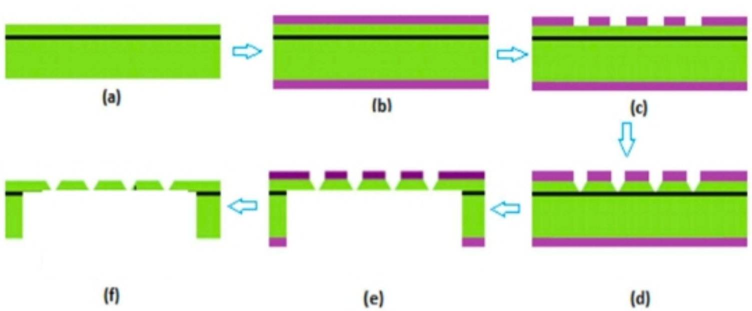


Photocathodes for the NCP

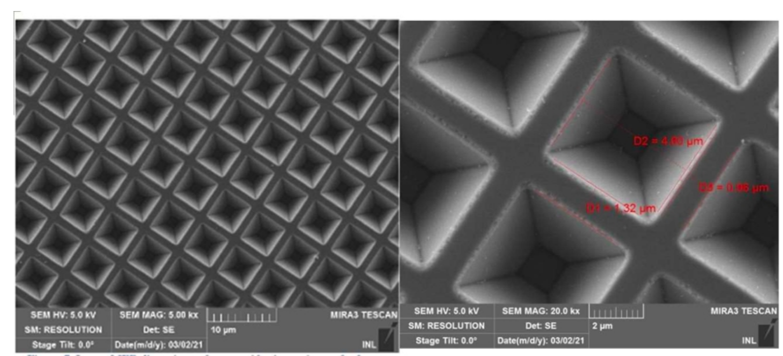
- In collaboration with INL at Lyon.

  We are using “Silicon on Insulator” (SOI) wafers to produce inverted pyramid that could coated and used as photocathodes with very high granularity.





a) Wafer SOI
b) Dépôt de nitrure
c) Ouverture du nitrure (Litho-Gravure)
d) Gravure humide KOH
e) Gravure face arrière ICP
f) Retrait nitrure

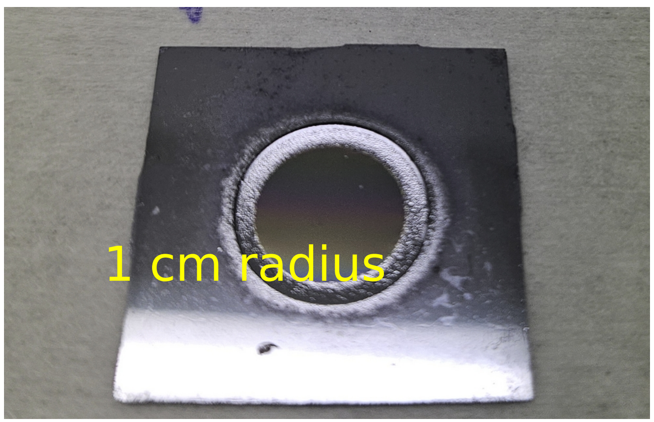


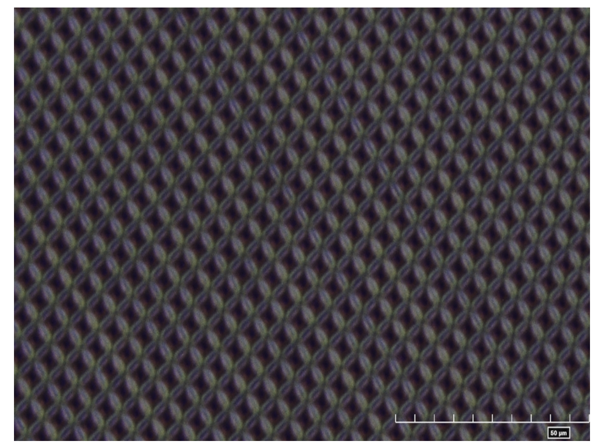
Photocathodes for the NCP

- In collaboration with INL at Lyon.

  We are using “Silicon on Insulator” (SOI) wafers to produce inverted pyramid that could coated and used as photocathodes with very high granularity.

Highly granular Photocathode





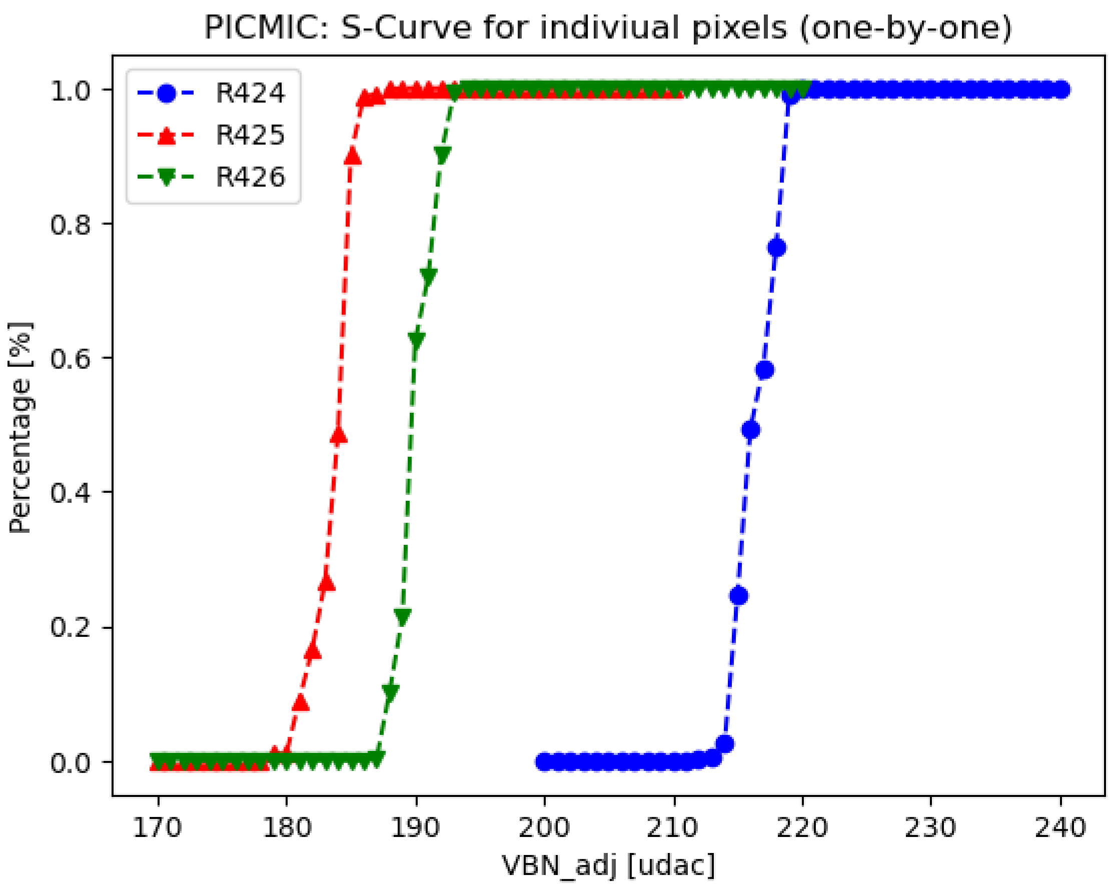
Photonis has produced a 1cm MCPs for us to be used with this future photocathode

Summary

- PICMIC concept **validated**:
  - Very precise time and positions measurement already validated.
- A first demonstrator using SAMPIC for time measurement and combining both time and position measurements based on SAMPIC DAQ is being used to combine both very precise time and position measurements.
- Test beam at ChannelTron (single e- beams, ILM)
- A new detector **NCP** is being developed to reach unprecedented resolutions in both time and position.
- Medical applications will greatly benefit from the new concept and associated developments.

BACKUP

Single pixel s-curves




```
df424.head()
```

	VBN_adj	Eff_trig	Unnamed: 2	Chip	Pixel	Run	VrefP	VrefN	VBN	VBP	Iadj
0	200	0.0	NaN	5	817	3	50	106	62	81	1
1	201	0.0	NaN	5	817	3	50	106	62	81	1
2	202	0.0	NaN	5	817	3	50	106	62	81	1
3	203	0.0	NaN	5	817	3	50	106	62	81	1
4	204	0.0	NaN	5	817	3	50	106	62	81	1

```
df425.head()
```

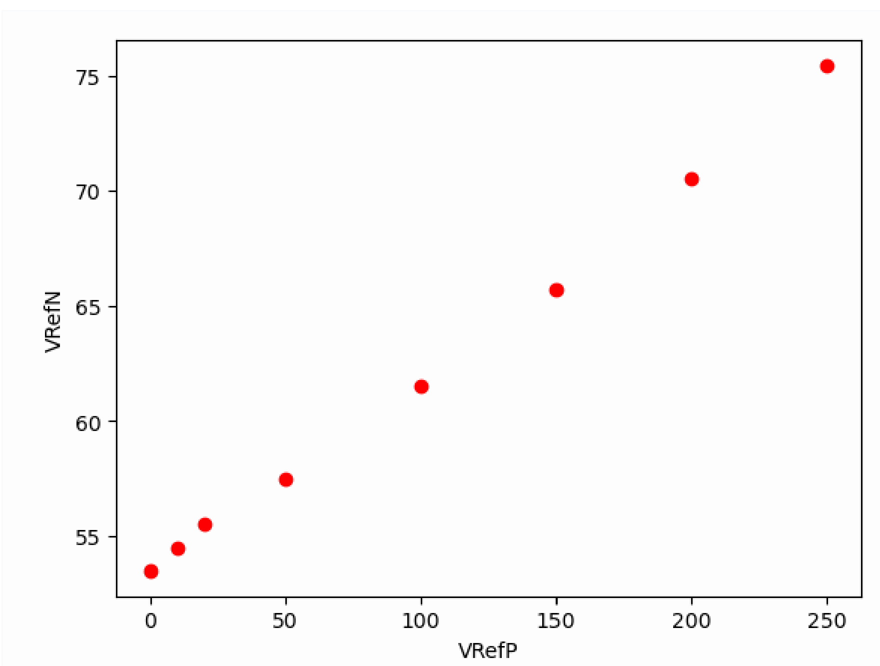
	VBN_adj	Eff_trig	Unnamed: 2	Chip	Pixel	Run	VrefP	VrefN	VBN	VBP	Iadj
0	170	0.0	NaN	5	817	6	50	106	62	81	1
1	171	0.0	NaN	5	817	6	50	106	62	81	1
2	172	0.0	NaN	5	817	6	50	106	62	81	1
3	173	0.0	NaN	5	817	6	50	106	62	81	1
4	174	0.0	NaN	5	817	6	50	106	62	81	1

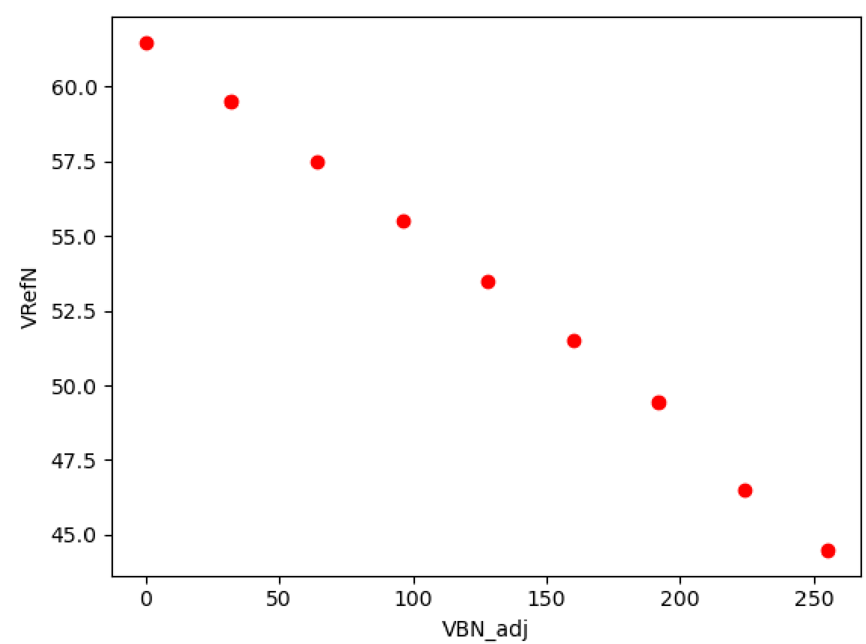
```
df426.head()
```

	VBN_adj	Eff_trig	Unnamed: 2	Chip	Pixel	Run	VrefP	VrefN	VBN	VBP	Iadj
0	170	0.0	NaN	5	817	1	130	106	62	81	1
1	171	0.0	NaN	5	817	1	130	106	62	81	1
2	172	0.0	NaN	5	817	1	130	106	62	81	1
3	173	0.0	NaN	5	817	1	130	106	62	81	1
4	174	0.0	NaN	5	817	1	130	106	62	81	1

s-curves [update]

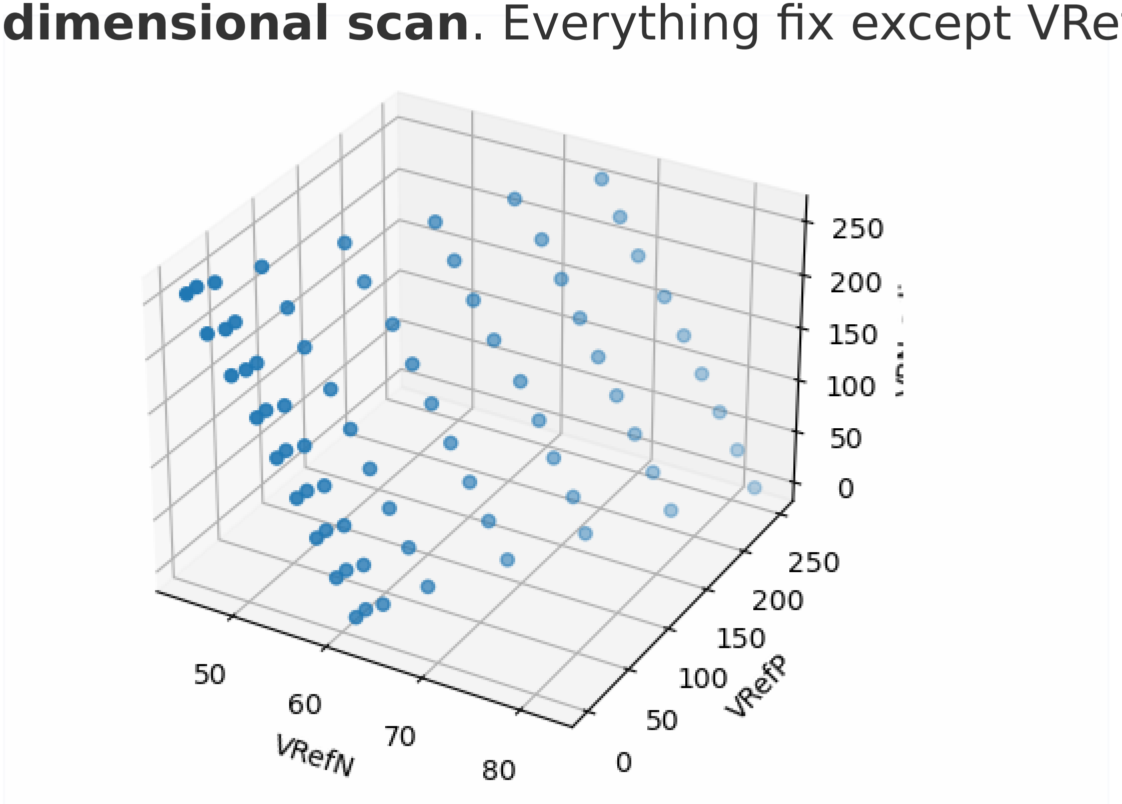
- Picmic has 5-DAC [VRefN,VRefP,VBN,VBN_adj and VBP]. Global variables.
- 2 local variables → Iadj<4bits> + SW<2bits>
- We started to performing studies to understand relationship between DACs[Globals] +and Local one.
- **Two-Dimensional scans :**
  - VRefN and VrefP Scan : VRefN and VBN_adj Scan
    - In both cases, nice linear trend





s-curves [update]

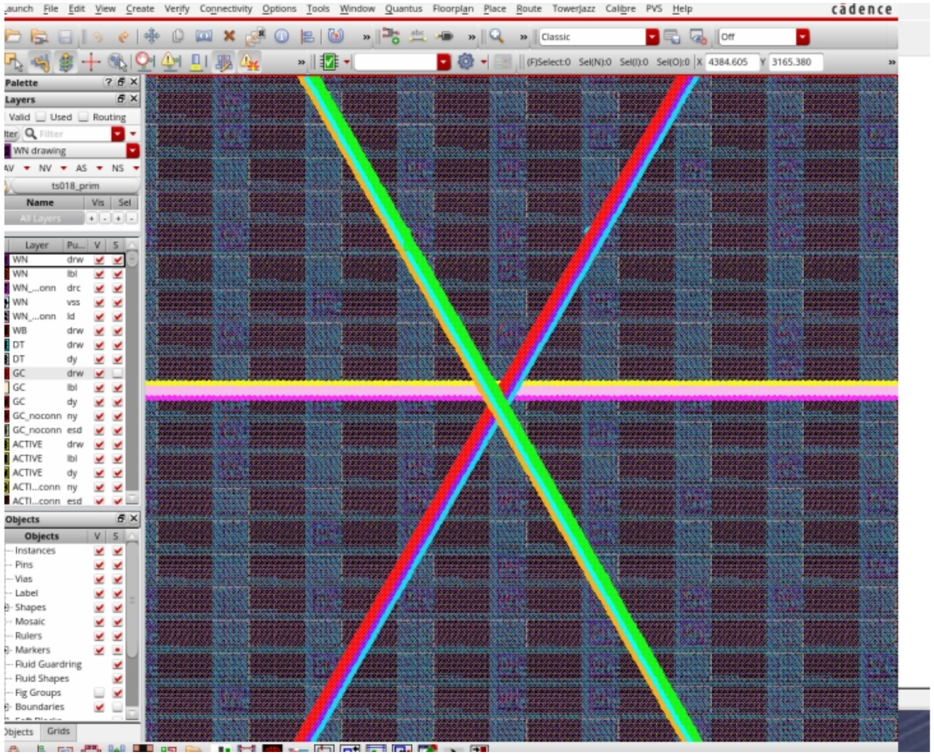
- Now, **Three-dimensional scan**. Everything fix except VRefN, VRefP and VBN_adj :

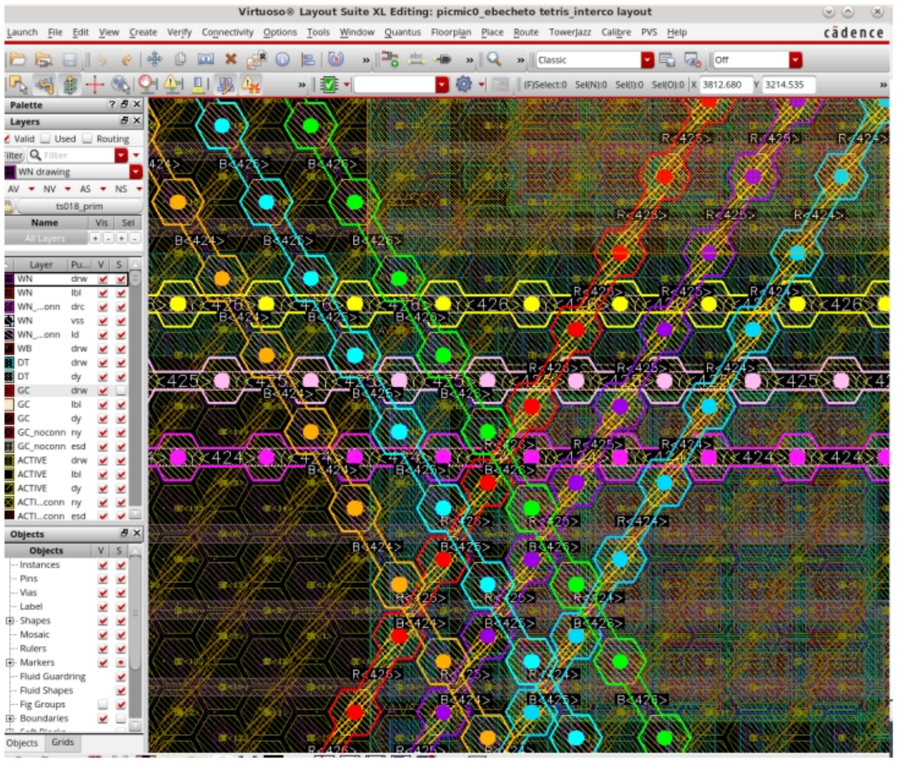


- It allows to see previous results and to define the following for the protocol:
  - Vg= VrefN*400nA-VrefP*80nA-VBN*80nA*10*(1.5 - 0.75*SW<0> - 0.5*SW<1>) (step 1)
  - Vl= iadj<2>*0.2+iadj<1>*0.6+iadj<0>*1 (step2)
  - – step1 → compute the mean value at 50% inflection point Vg
    – step2 → from step1 estimate values in DACs, then fine tune using locals .
    - As already shown in the last meeting

Effects # of ways in sCurve Scan

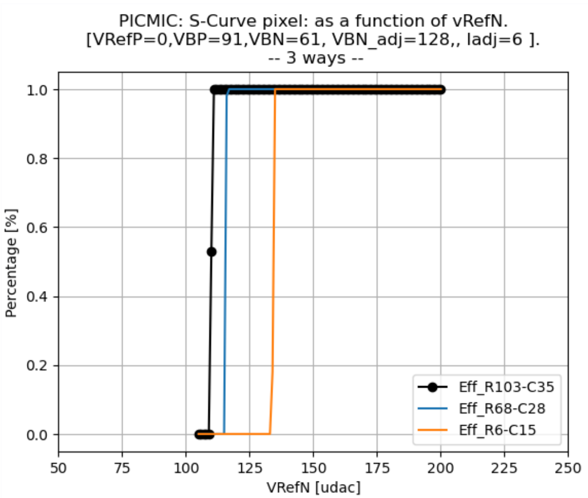
- In order to reduce the iteration time (data production), we studied the effect as is affected the sCurve for a way according the number of ways added together

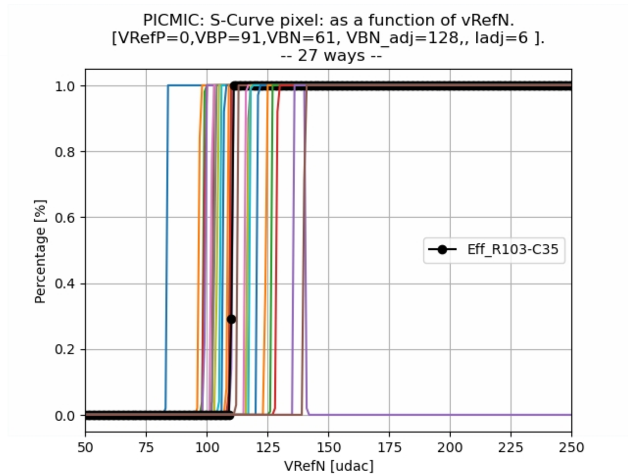


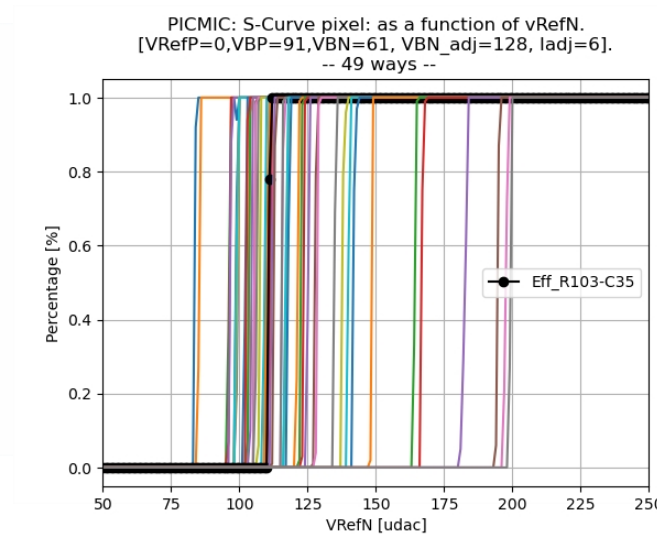


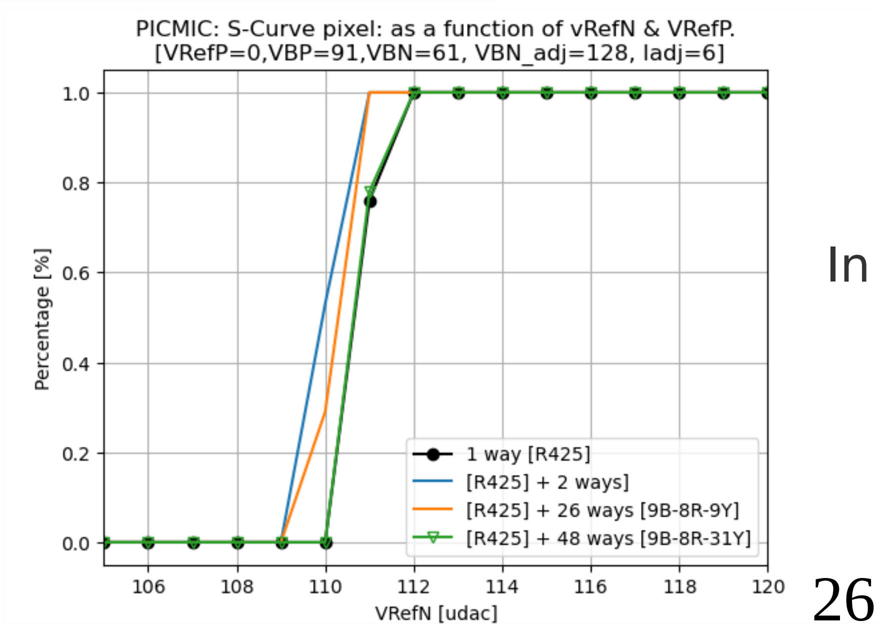
Effects # of ways in sCurve Scan

- In order to reduce the iteration time (data production), we studied the effect as is affected the sCurve for a way according the number of ways added together





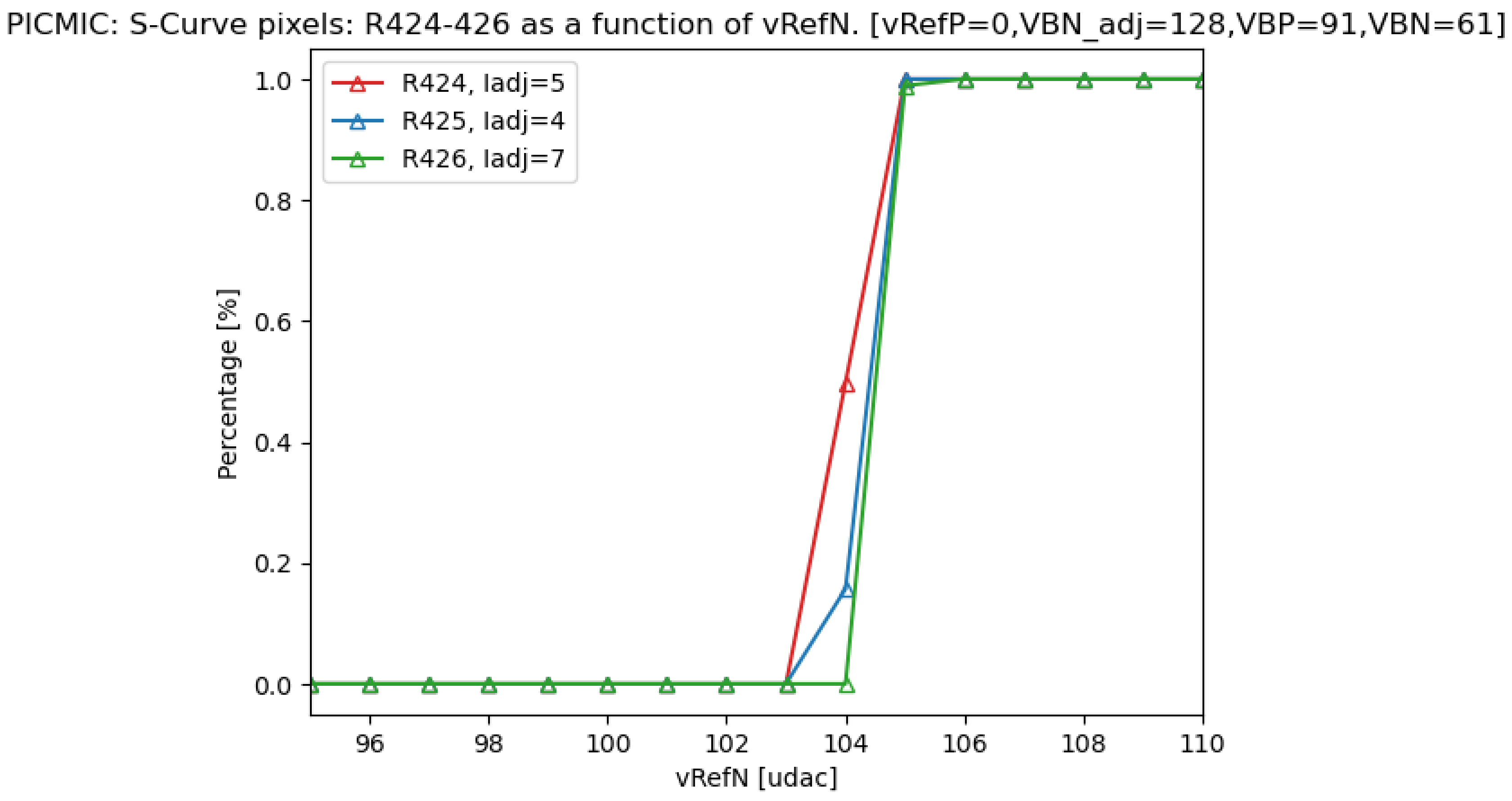




In agreement within 1 [udac]

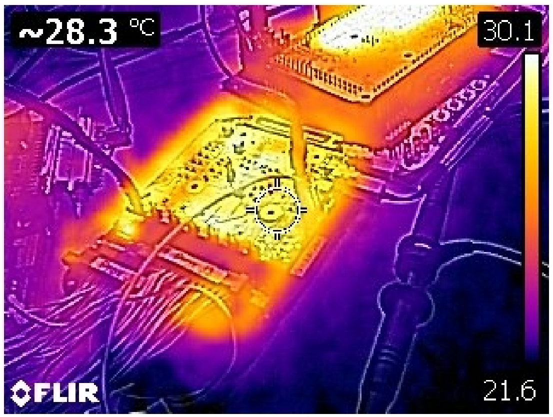
Injection [update]

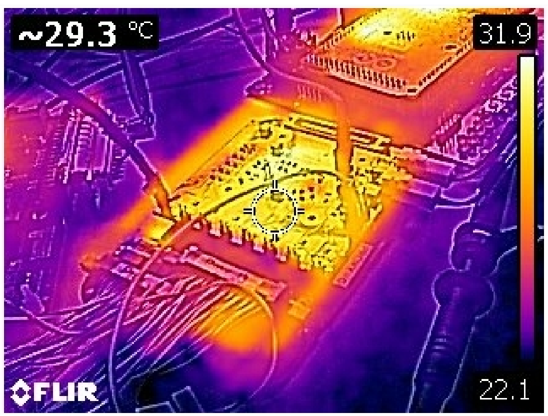
- We roughly know how to melt a few curves. So, lets try again signal injection for three pixels studied previously (R424, R425 and R426) his effect over there.
-

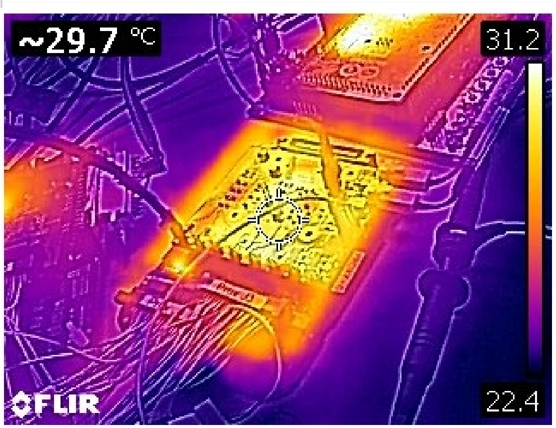


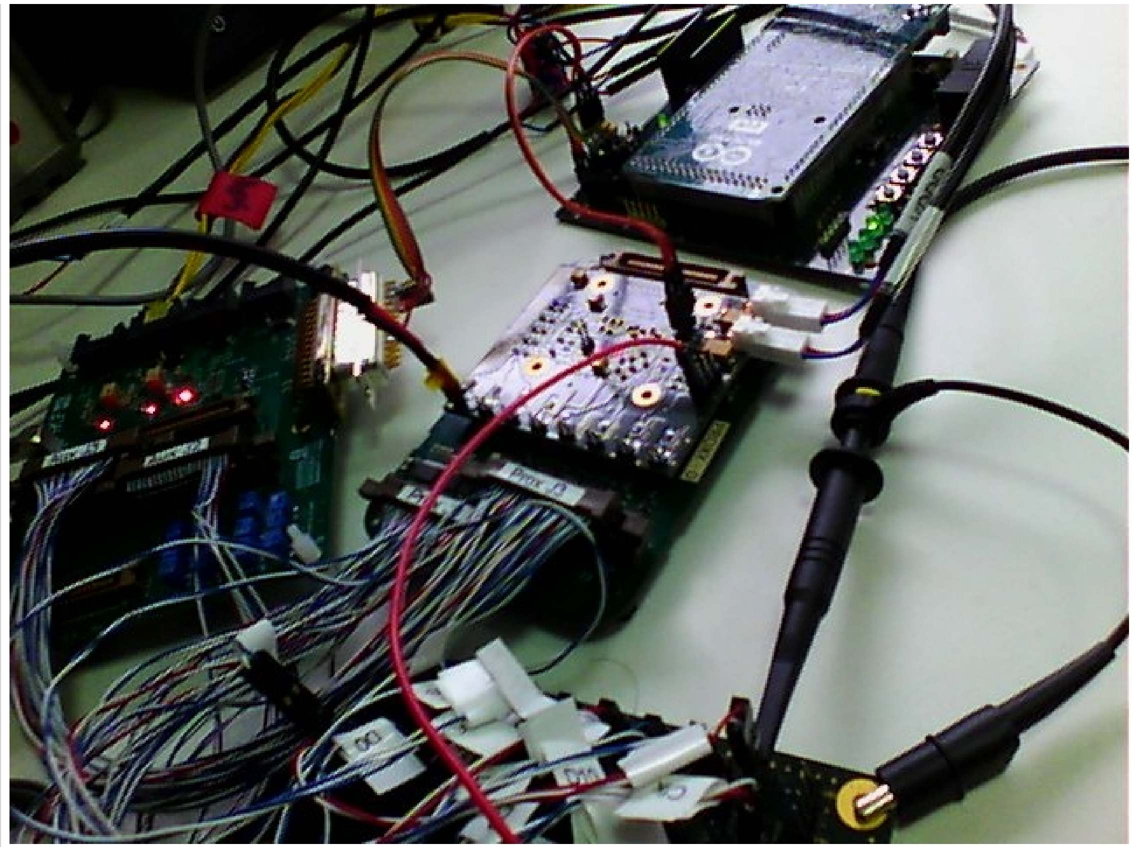
S-curves in three ways after calibration.

Temperature Tests









- Temperature lows and stables during DAQ scans (ON during several days).
- Effects within 1[udac] in VBN_adj(low current step) value scans.

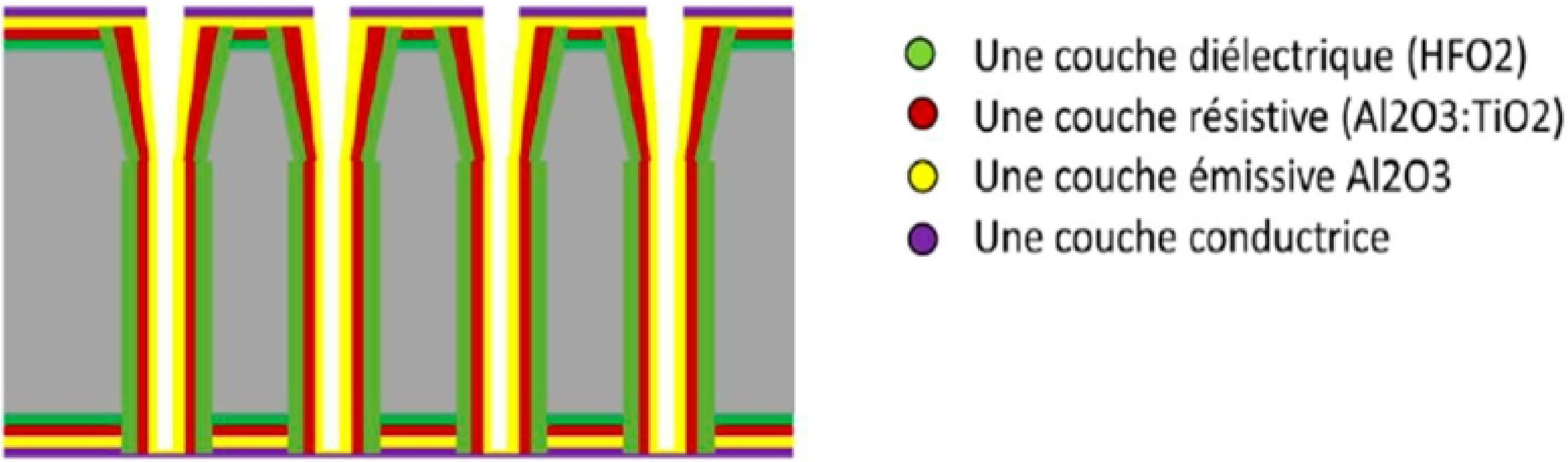


Figure 52. Structure imaginée pour la fonctionnalisation du NCP

Figure-2 shows data from a front-front mercury probe measurement indicates that resistivity (determined to an multiplicative constant associated with the geometry of the Hg-probe contacts) is a strong function of thickness for films thinner than 30nm.

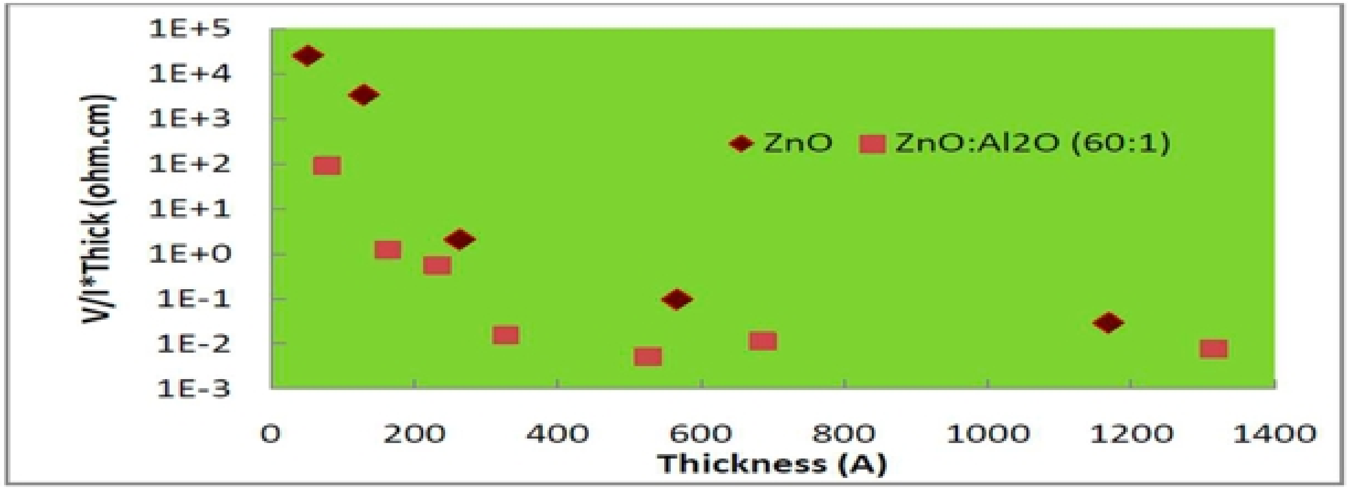
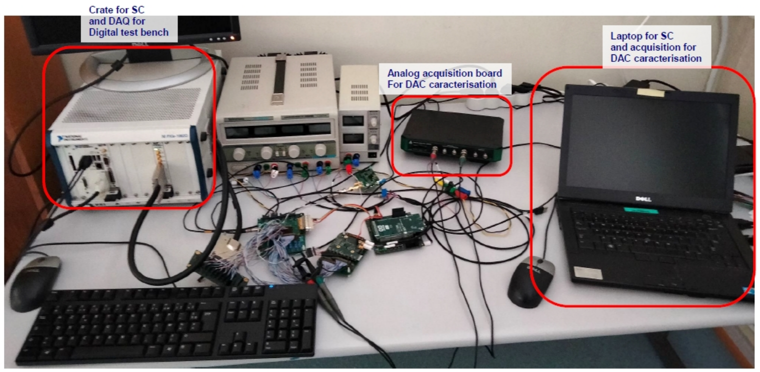


Figure-2

Test Bench



- Test bench HW developed by IPHC
  - New design for sensor board & Arduino shield
  - Most of the test bench **HW reused** from a previous project
  - I2C: Arduino DUE board
  - DAQ: NI PXI6562 board 16 I/O up to 200 MHz

PICMIC DAQ Sequence Schematic: