Development of the PICosecond subMICrometer (PICMIC) detector

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on behalf of

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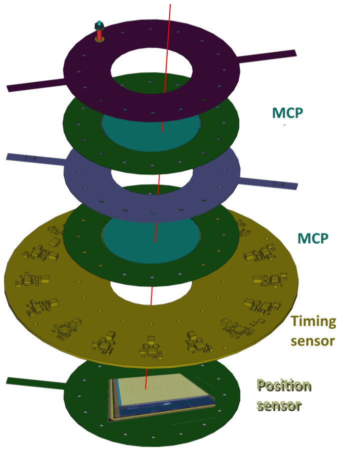
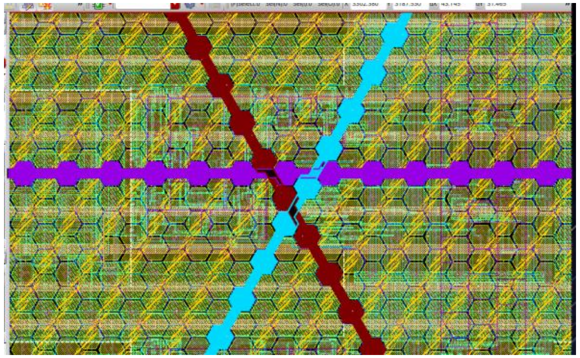
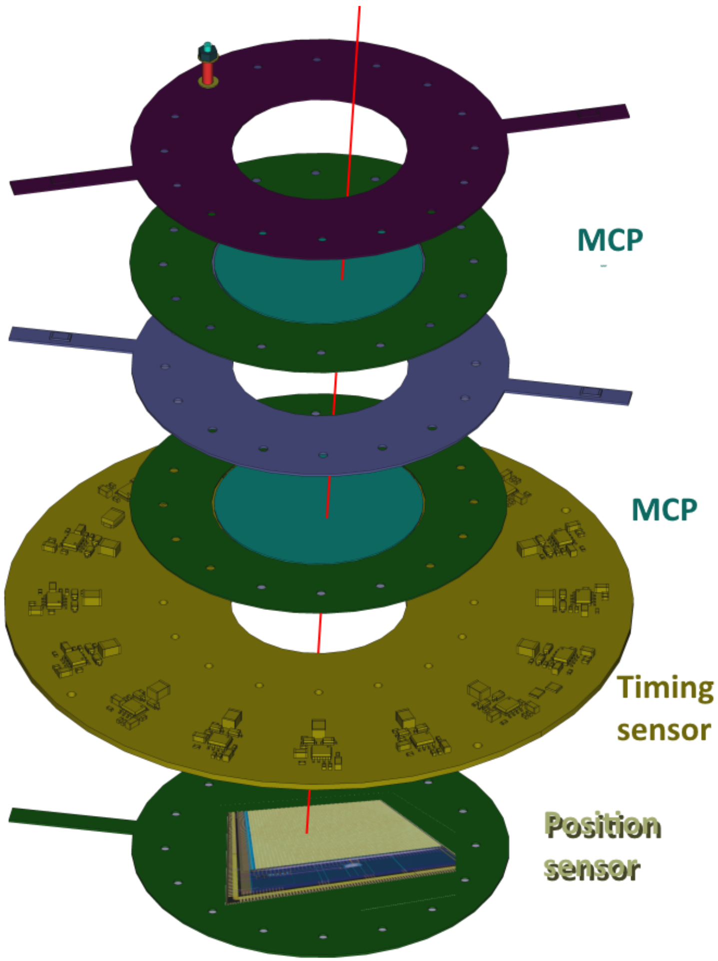




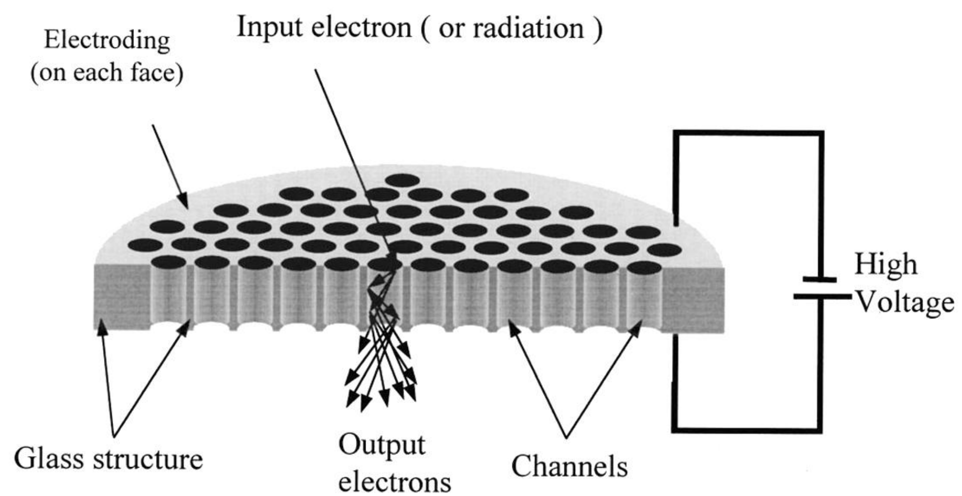
Outline

- PICMIC concept
  - Time measurement
  - Position measurement
- Detail of the position sensor prototype
  - Layout of 3D view
  - Architecture
- Experimental results
  - Threshold S-curves
  - Position measurement of injection probe
  - Test with α and γ sources
- Next step
  - Large area position sensor PICMIC-1
  - PICMIC with Nano-Channel Plate (NCP)
- Summary

PICMIC concept

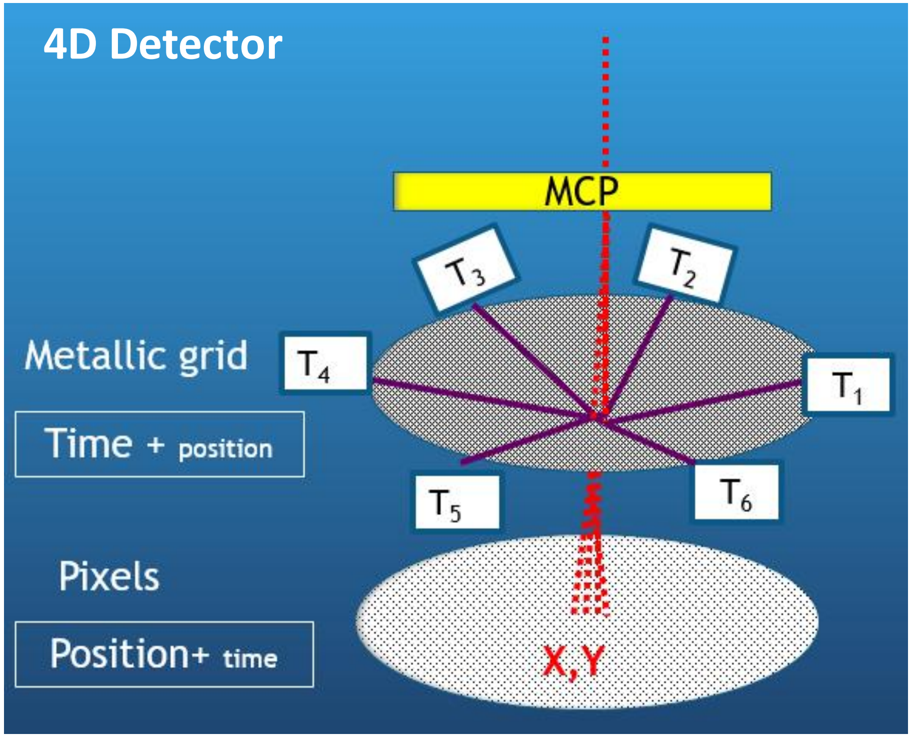


- MCP is as for now is one of the best timing devices with a few picoseconds of resolution.
- MCP has an excellent intrinsic spatial resolution since the avalanche produced by the incoming particle is constrained to one of the glass tube whose diameter can ban as small as a couple of µm.
- MCP are often used for their timing while their spatial resolution is not appropriately exploited.



PICMIC concept

- **To fully exploit MCP a new scheme is proposed**
  - A transparent grid placed downstream the MCPs and read out by sensors with excellent time resolution.
  - A detection matrix with small pixels to measure the position of the avalanche while requiring limited number of electronics channels.



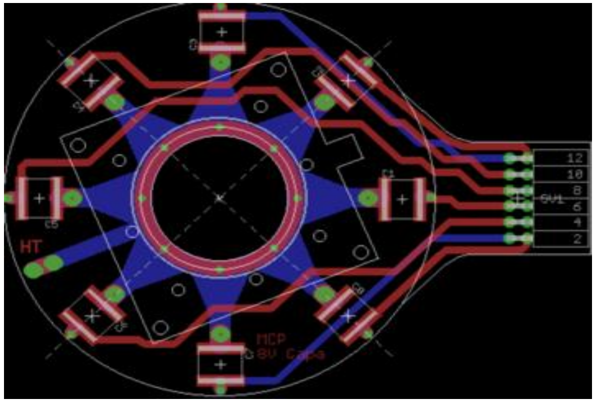
Concept description

- The avalanche crosses a transparent grid connected on its periphery to a few timing sensors.
- The avalanche is then collected by pixels.

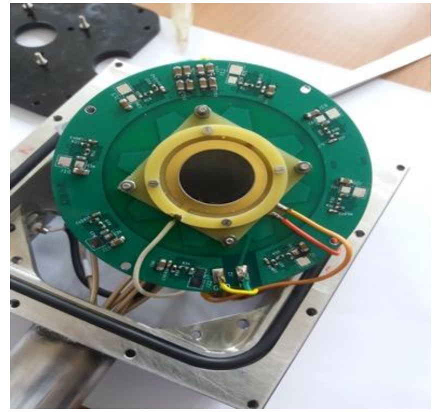
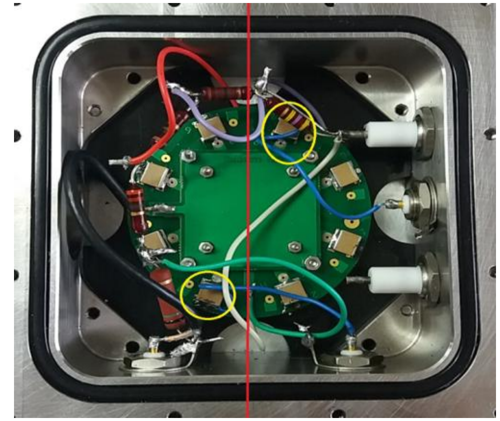
1. Measure X,Y, by the fired woven strips
2. Measure T_i by time sensors
3. Subtract time propagation using speed propagation
4. Average value on the $(T_i - T_{i(propag)})$

$$T_{abs} = \frac{\sum_1^N (T_i - T_{i(propag)})}{N}$$

Time measurement

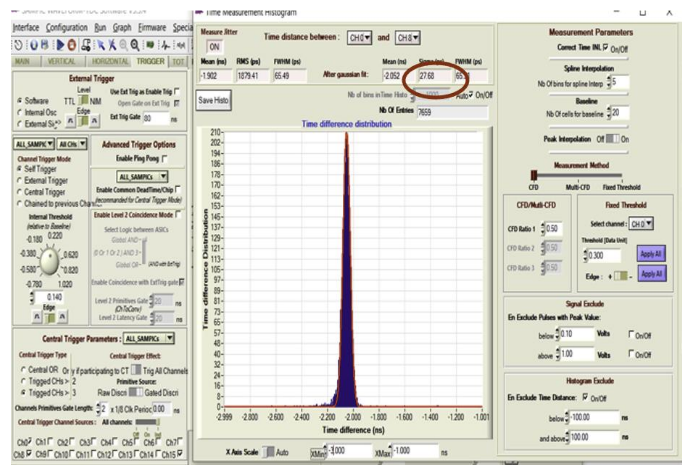


8-point PCB for the time measurement.
PCB to be in contact with the grid

System tested on 2-MCP system of 25mm diameter using α source

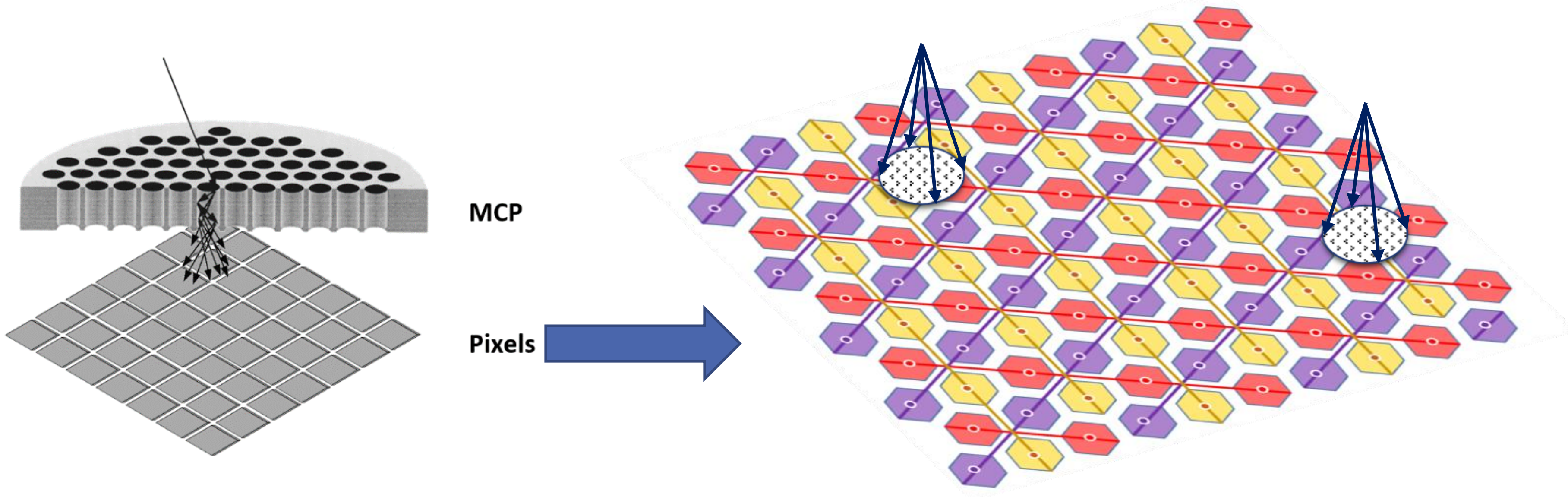
SAMPIC: TDC ASIC allowing
to reach 3 ps time resolution



Time resolution of arrival time of two channels is of 30 ps → 10 ps by exploiting 8 channels

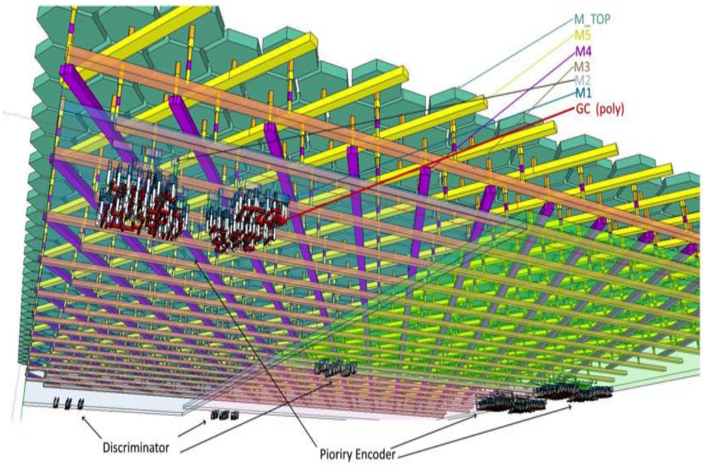
Position measurement

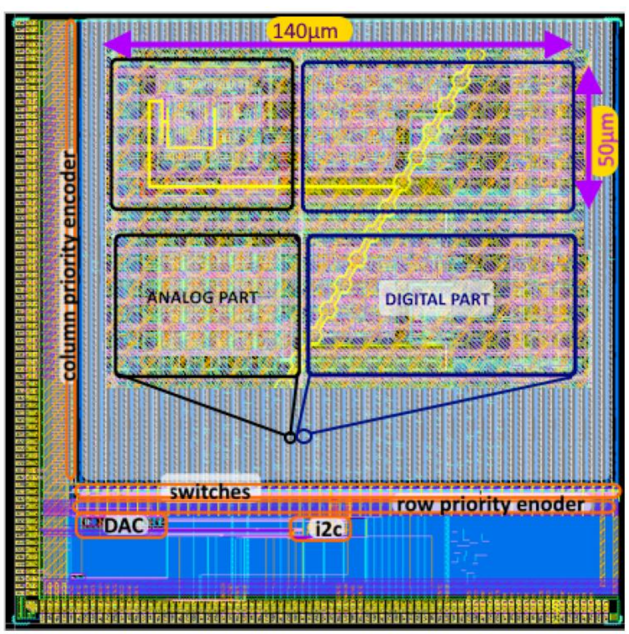
- **To reach few microns resolution with a limited number of electronic channels, a new concept was developed.**
  - Connect the pixels in woven strips
  - Two neighboring pixels are connected to two different strips
  - Each strip is connected to one electronic channel
  - Share the charge among a few ones
  - Crossing the fired strip to determine the position



N × N → 3N : Reduction of electronic channels, power consumption and occupancy

Position sensor prototype: PICMIC-0

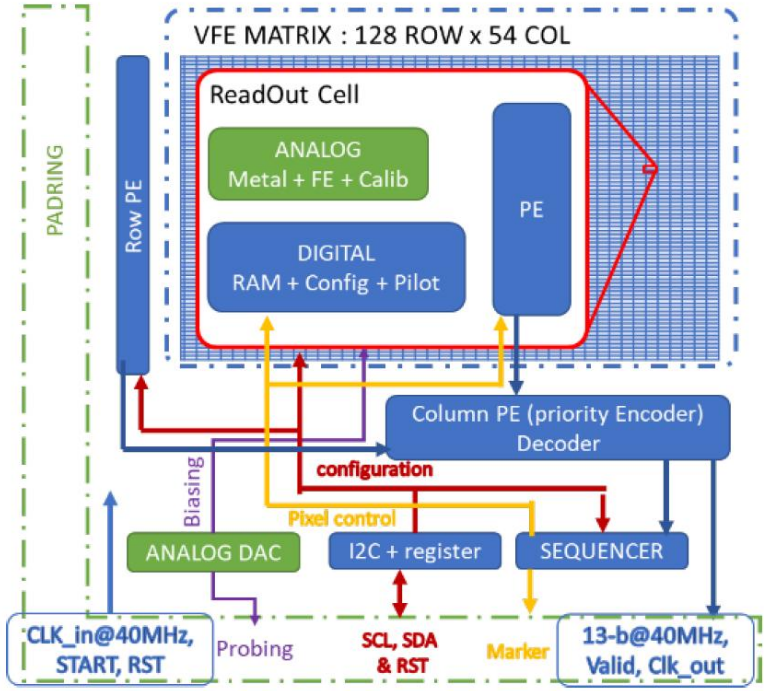




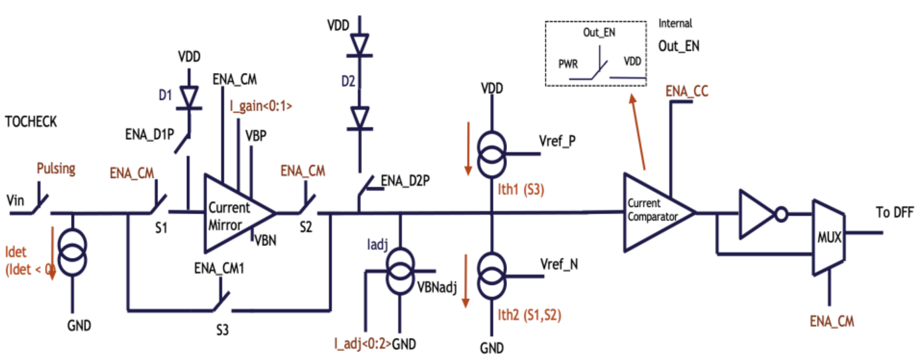
- Although there is no silicon sensor, the CMOS technology was used.
- Pixels, the interconnections as well as the readout electronics are implemented in TJ 180 nm (6 metal layers) technology.

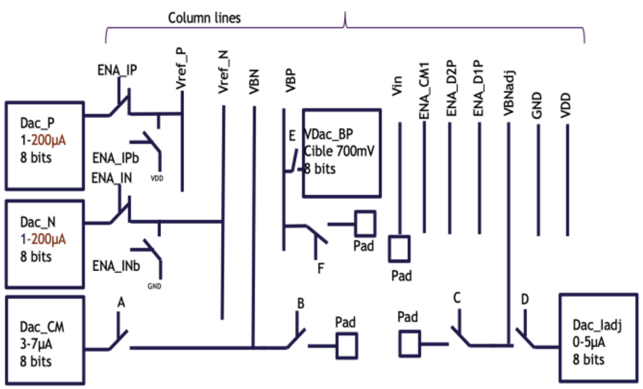
Parameters	Value
Design Flow	Cadence DoT flow
Technology	TJ CIS 180nm
Power supplies	1.8V
Power density	>172mW/cm^2
Die dimension	~7.5x7.5 mm^2 (6.5x7.5mm^2 active)
Anode dimension	~22µ^2(5µm hexagonal pitch)
Readout pixel dimension	50µmx140µm
Readout matrix	128x54 cells (only 2556 active)
Input clock	40MHz
Read-out port	13-bit parallel, 1 sync clock out, 1 marker
I/O Pad	CMOS
Slow control	I^{2}C
Max data rate (1Mhz hit rate)	390Mbps

Position sensor prototype: PICMIC-0



- Current conveyor preamp followed by a comparator. They are optimized to cover the dynamic range of a single and a doublet MCP.
- 5 DACs are used to control the preamp and the comparator response globally.
- One DAC (3-bit) to correct the threshold of each cell individually.
- Priority encoder protocol is used to read out only the cells with data.

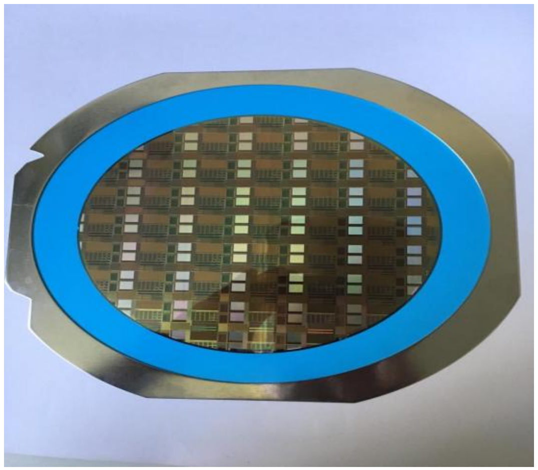




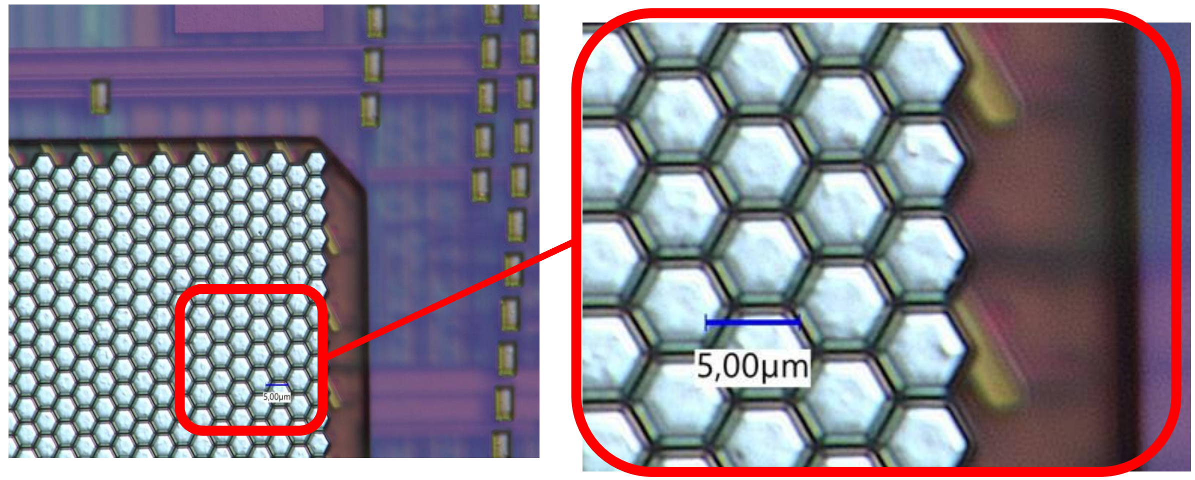
Position sensor prototype: PICMIC-0

Prototype chip and test bench

The chip was submitted in November 2021 (TowerJazz) and received on July 2022

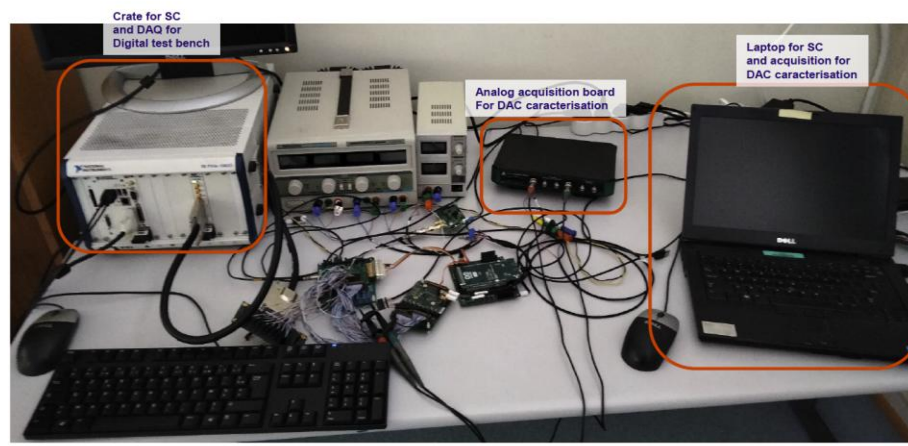


TJ wafer



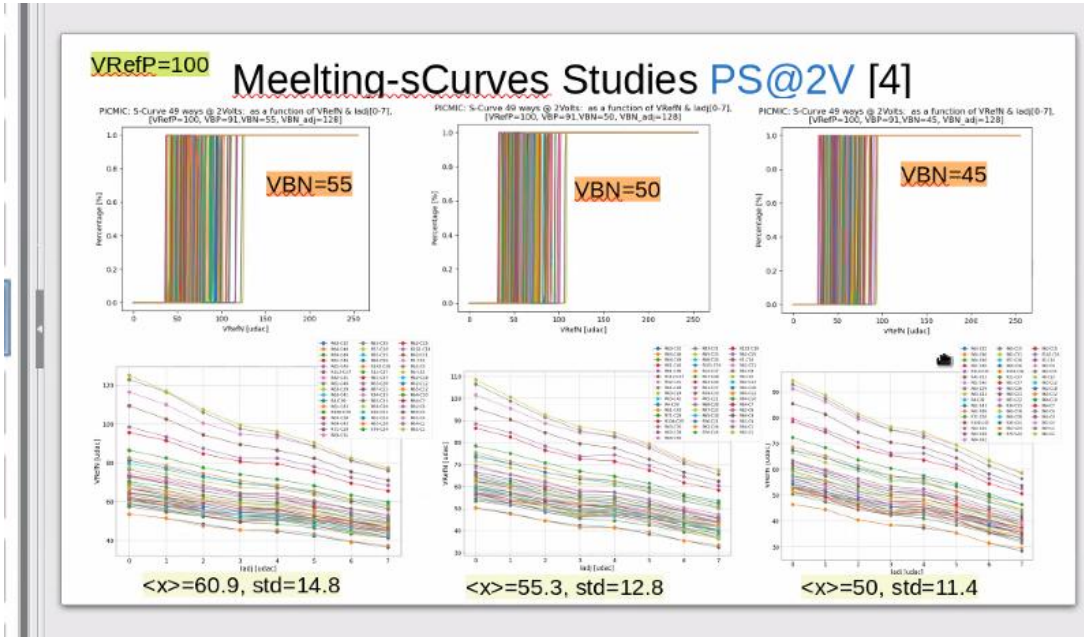
Hexagonal pixels

Test board

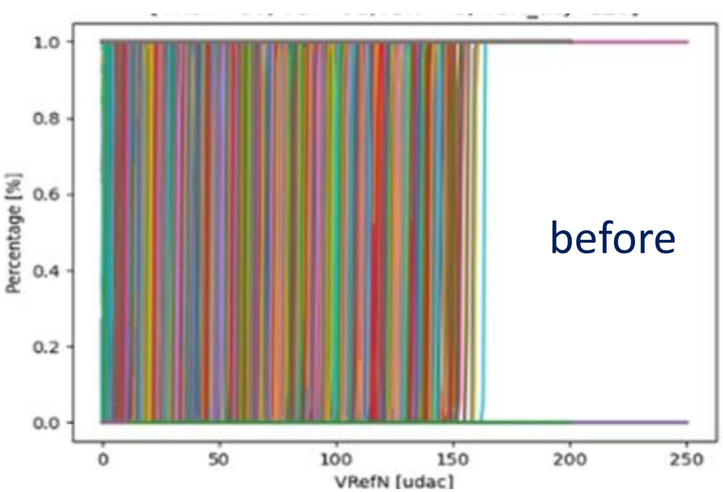


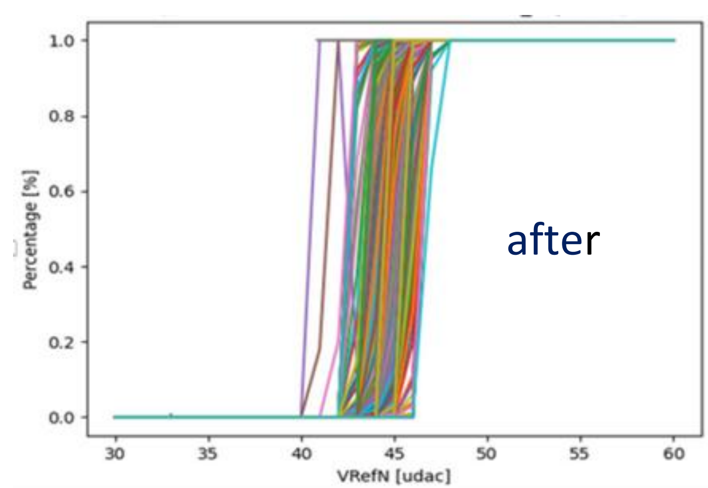
Test bench

Position sensor test



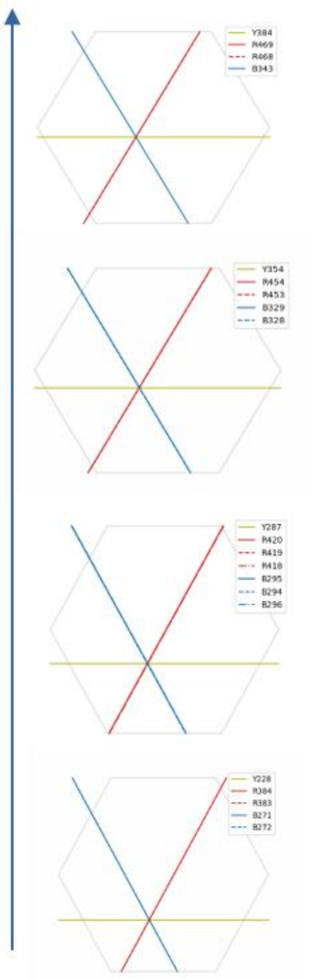
- ❑ Pedestal S-curve calibration
- ❑ A scan of all the DAC values was performed to find the best operational point
- ❑ Threshold spread as function of the global current parameter
- ❑ The adjustment of the 3-bit inner readout-cell local current source permits to adjust the 50% crossing of the S-curve

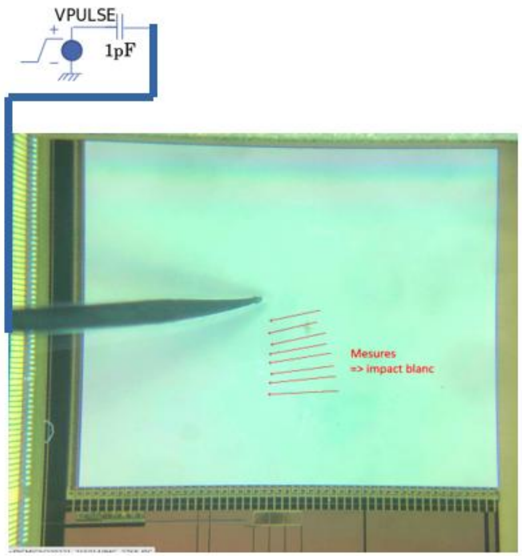


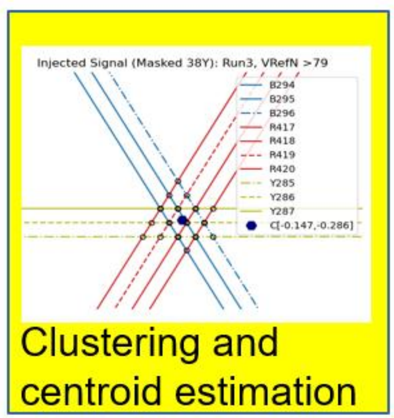


Position sensor test

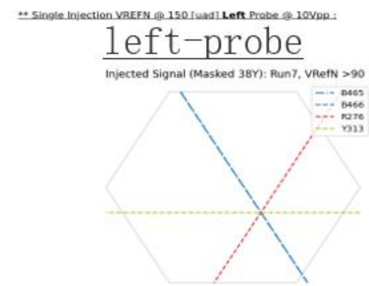
- Test with direct injection of charges using probes

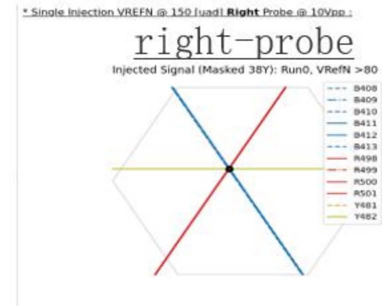


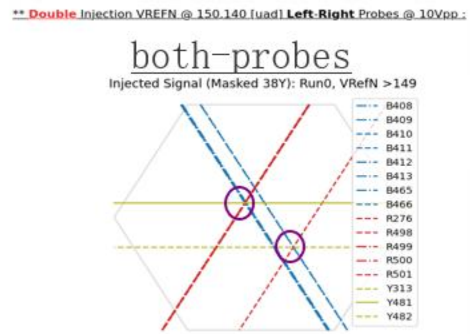


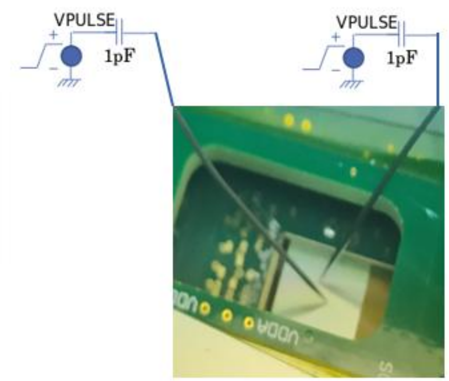


One probe injection





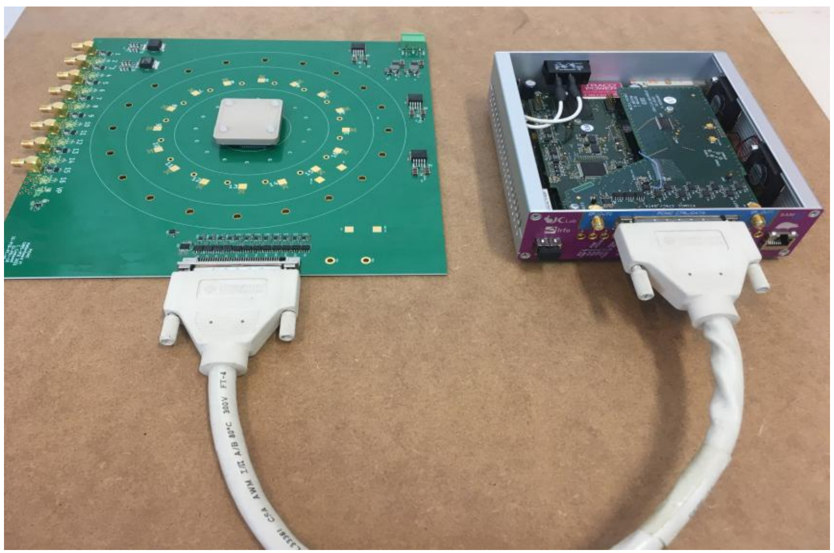


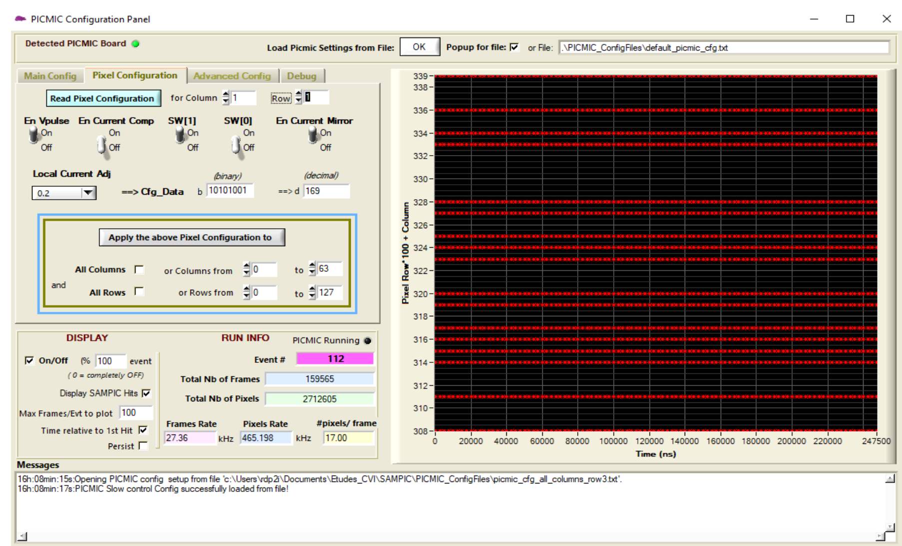


Two probes injection

PICMIC DAQ

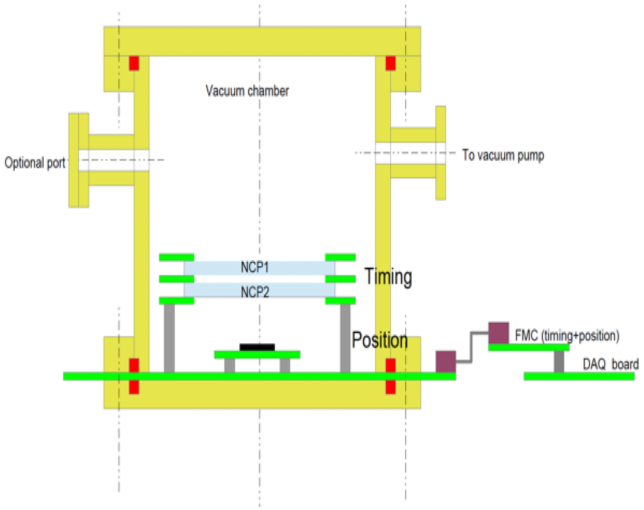
- ❑ With both time and position sensors tested, a dedicated DAQ board was developed
- ❑ Distribute the same clock (40 MHz) to both the timing and position chips
- ❑ Collect data from both and associate them
- ❑ The DAQ board was placed within the SAMPIC module.

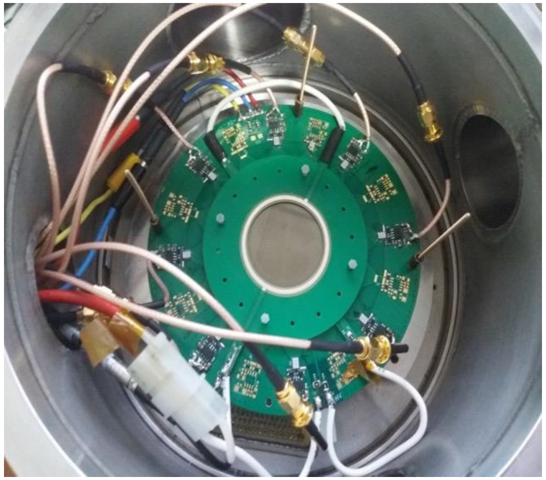




PICMIC demonstrator

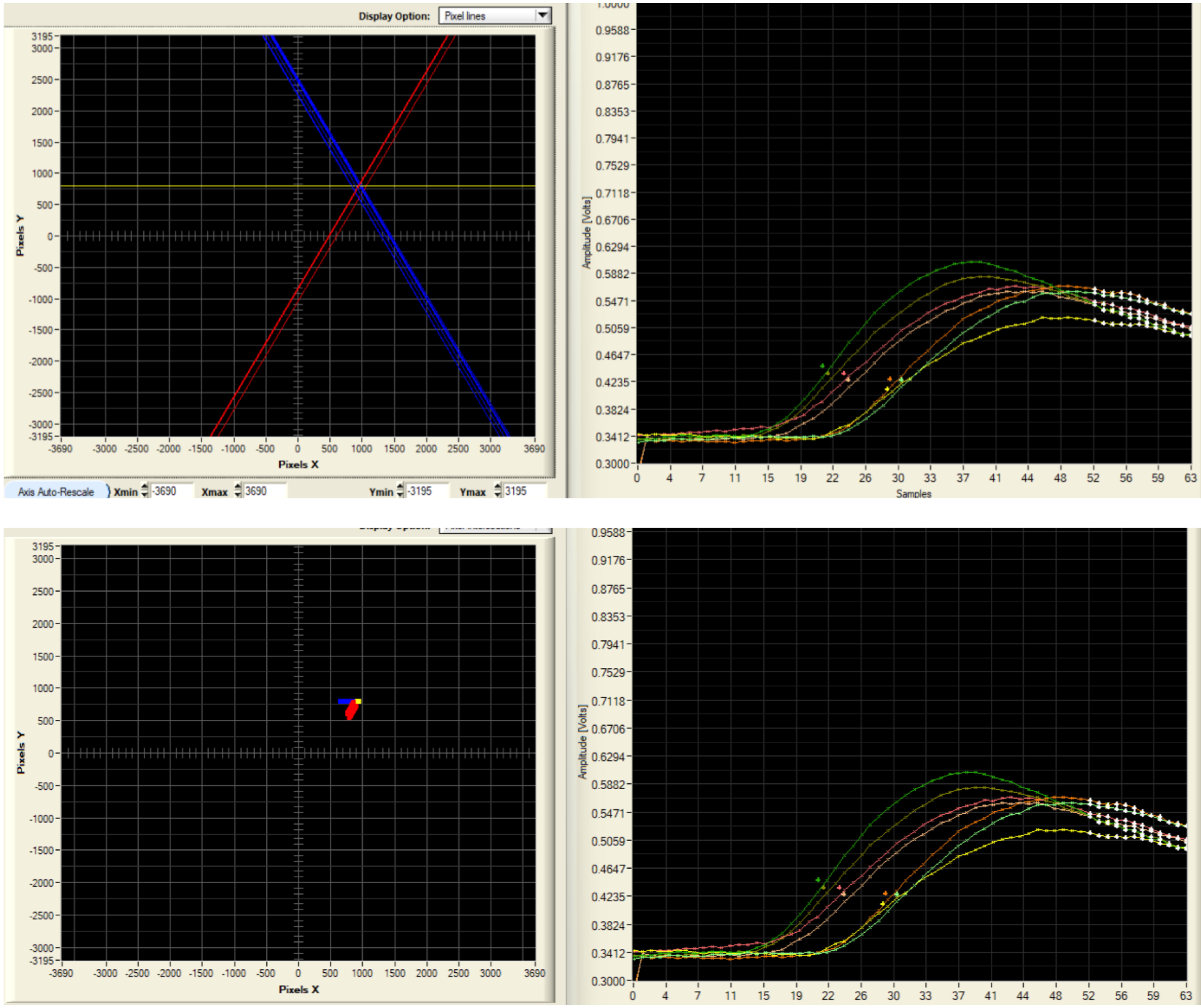
- The first prototype including:
  - Two 5-cm diameter MCP
  - A board hosting 16 timing sensors (only 8 were cabled)
  - A mezzanine hosting the pixel sensors
  - A Master board
- All are placed within a vacuum system (<10e-5 mB)





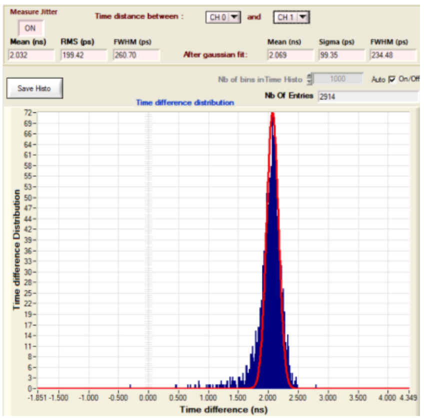
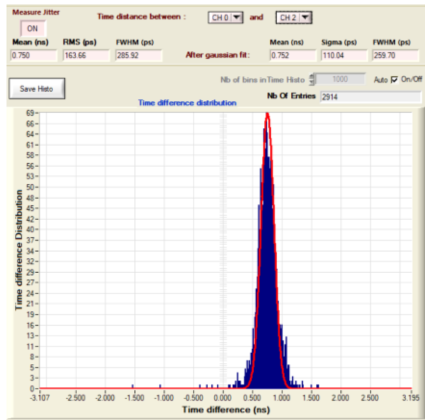
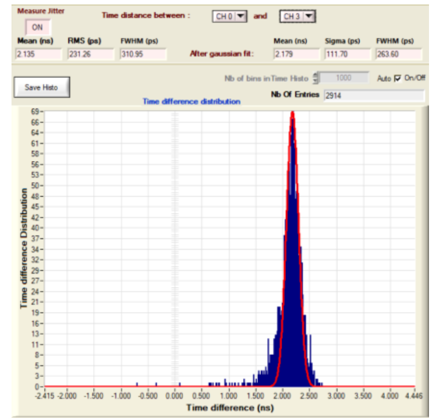
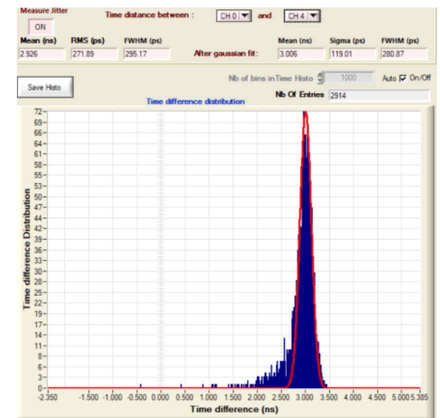
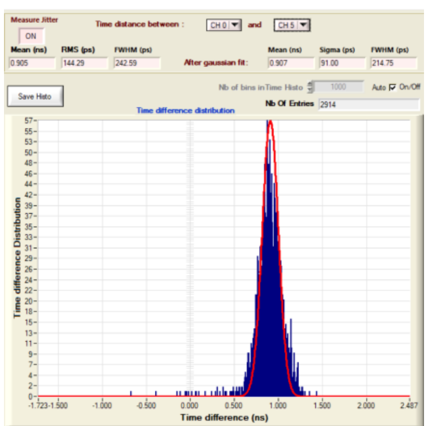
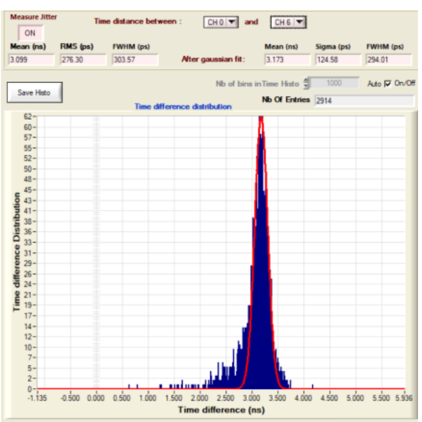
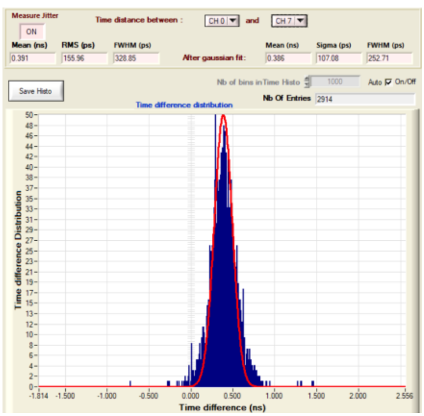
PICMIC demonstrator

- ❑ The whole system was tested by using collimated α and γ sources



PICMIC demonstrator

- Histograms of arrival time difference of Ch1,Ch2, Ch3, Ch4, Ch5, Ch6,Ch7 and Ch0

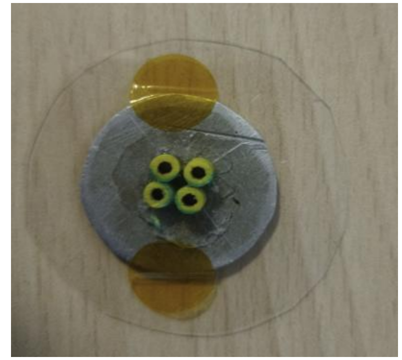








$\sigma(T_i - T_j)$ is 100-120 ps → σ_{abs} is around 25-30 ps

PICMIC demonstrator

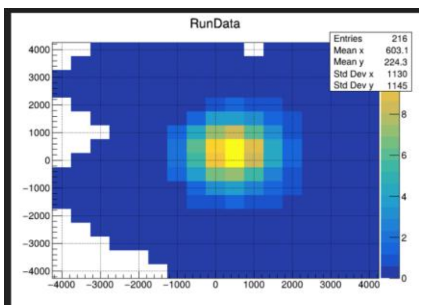
❑ The whole system was tested by using collimated α and γ sources

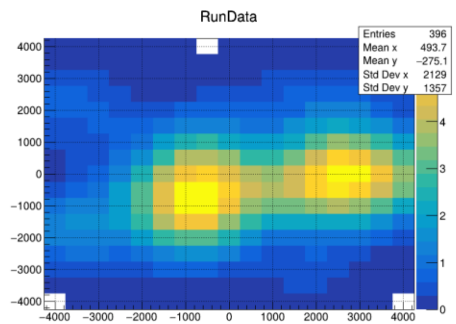

1 mm holes

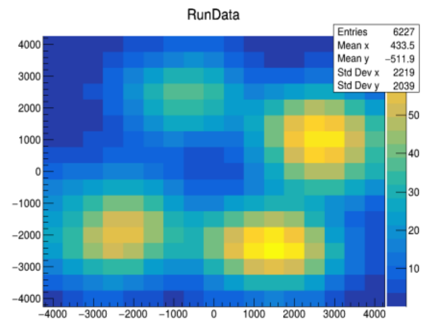


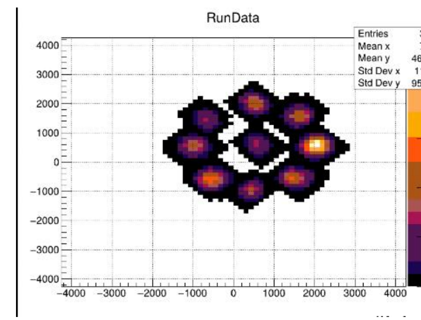
2 mm holes

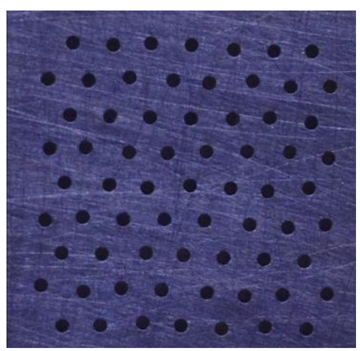
0.5 mm holes

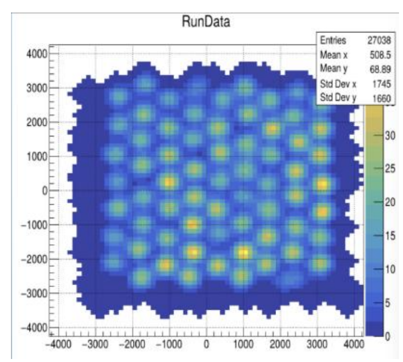








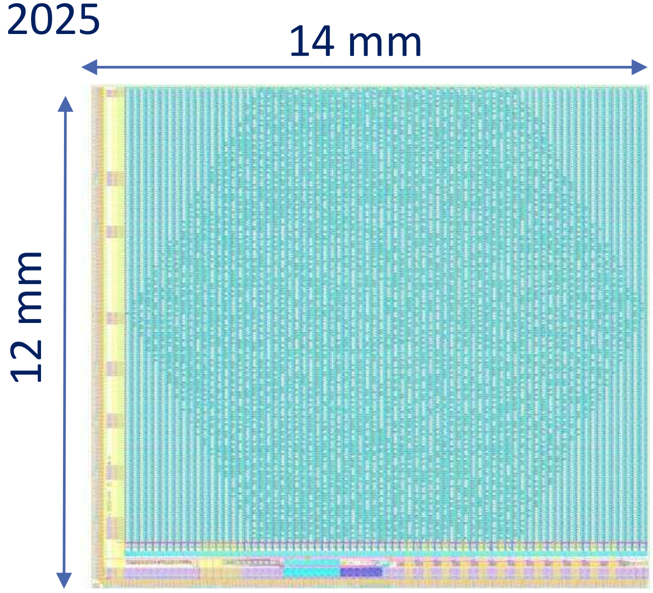




Many holes of 0.3mm diameter and 0.8 mm pitch

New position sensor prototype: PICMIC-1

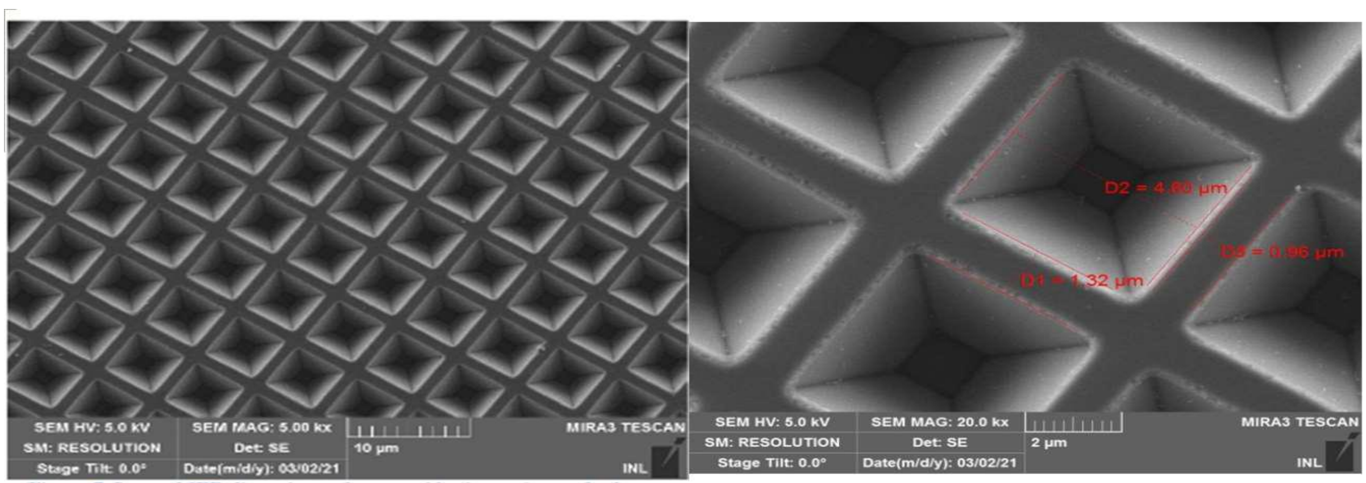
- The PICMIC-0 chip was the first attempt to demonstrate the concept. PICMIC-1 was improved on several features.
  - Better calibration possibilities (8 bits DAC) to get better uniformity
  - Higher acquisition rate (1 MHz → 10-30 MHz)
  - By reading out each column separately
  - By increasing the surface of the sensor by a factor of 4 (1.2 cm x 1.4 cm)
  - Adding a charge preamplifier to avoid current smearing problems for long tracks
  - Submitted in May 2025



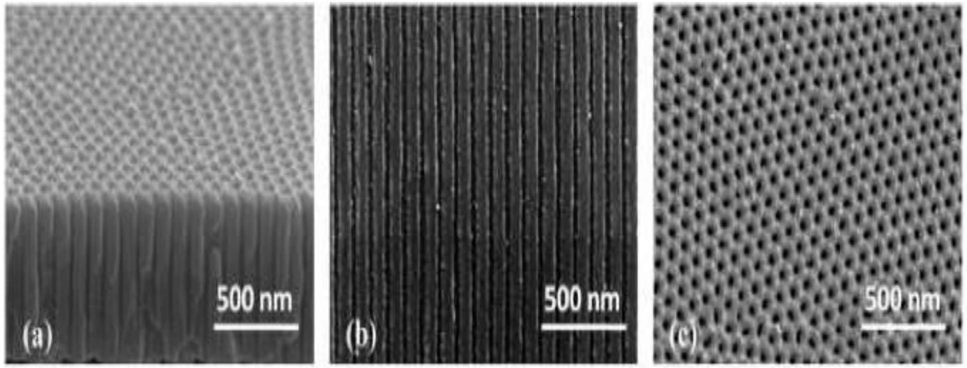
PICMIC-1

Next step: PICMIC for photodetection

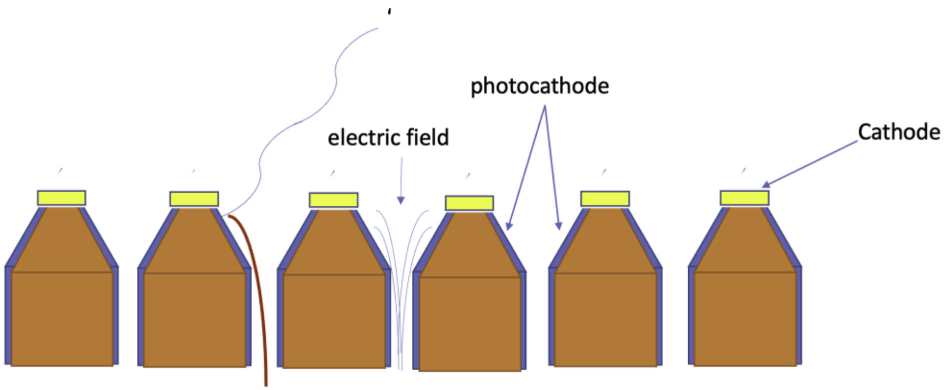
- A highly granular reflective photocathode is being developed. Photocathode is made of holes with conic shape.
  - Exploit the high spatial resolution the MCP offers
  - Increase the quantum efficiency
- The structure will be coated with different kinds of photocathode materials and then cast on MCP to test PICMIC as a photodetector concept.



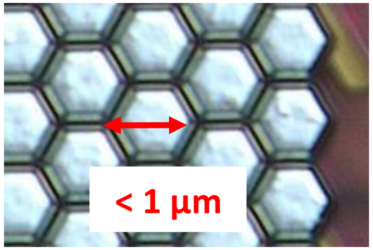
Next step: PICMIC with Nano-Channel Plate (NCP)



- A new kind of MCP that we call Nano-Chanel Plate (NCP) is being developed.
  - Small aperture
  - Large aspect ratio: L/d, ultra-fast response time
- It aims at producing structures with nanoholes that could be coated with emissive and resistive materials.



- Three technologies are followed
  - Anodized Aluminium Oxide (AAO)
  - Silicon electrochemical etching
  - Femto-laser digging
- More precise time measurement with a dedicated ASIC
- Position sensor developed in smaller process like 65nm or less
  - More metal layers, less power consumption, high speed



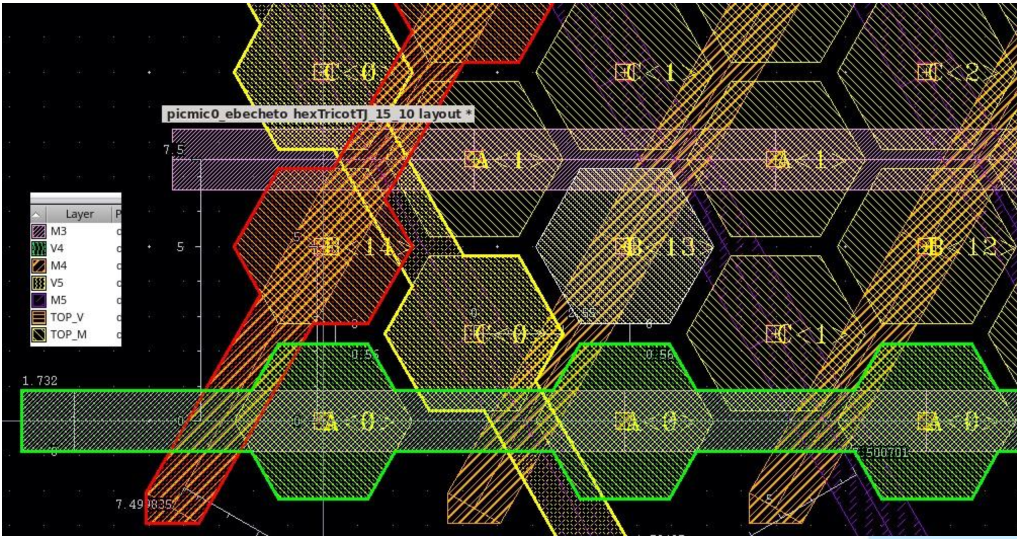
Summary

- The PICMIC concept that allows to simultaneously measure the time and position of MCP is validated
- Optimization and independent resolution measurements are ongoing
- High-rate capability with large surface device has been submitted
- New high granular reflective photocathode is being developed and will be soon tested on MCP
- A new generation called NCP with the aim to reach 1 ps and sub-micrometer resolutions are being developed

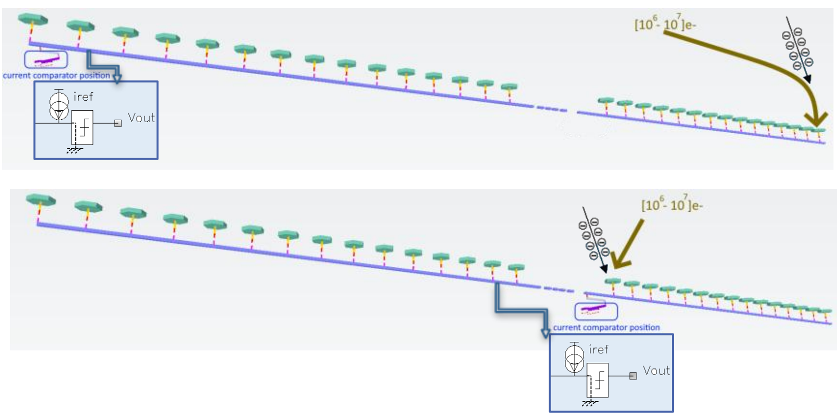
Thanks

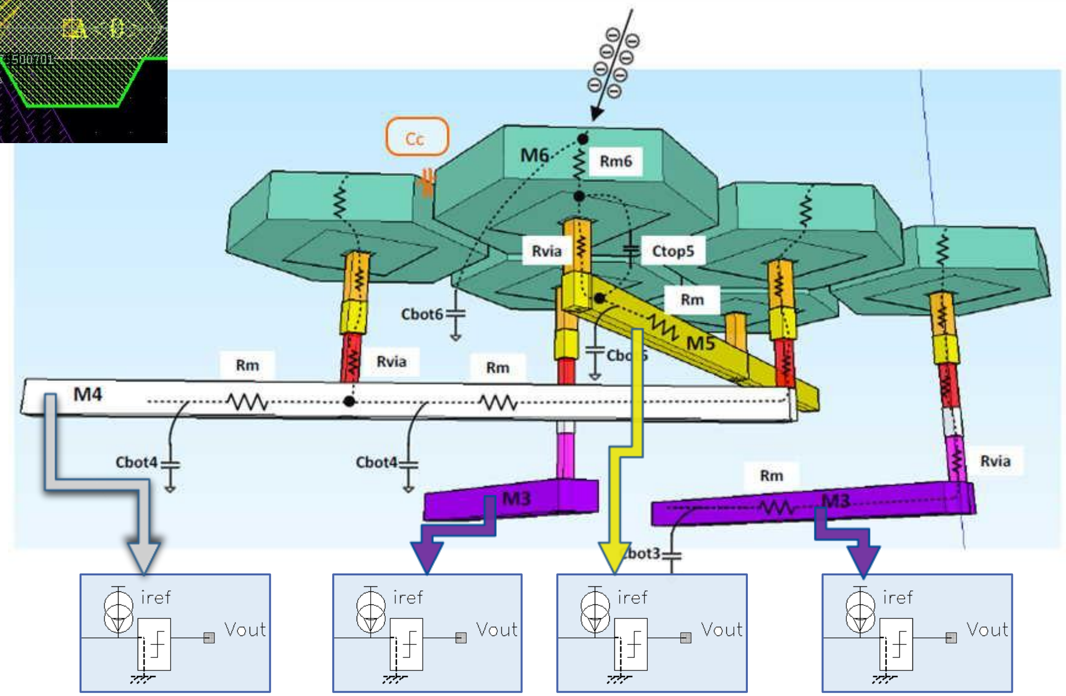
BACKUP

	PICMIC-0	PICMIC-1
Taille du circuit	8.4 mm * 8.4 mm	16.4 x 14.76 mm^2
Taille de la matrice de pixels Nb lignes(ROW) * nb colonnes(COL) Dimensions d'une cellule active Voies de lectures actives	7.4 mm * 6.4 mm (0.5cm^2) 128*53 140µm x 50µm 3*852=2556 canaux	**14.8 mm x 12.8 mm (1.9cm^2)** 184 x 74 199.92 um x 70 um 3*1704=**5112 canaux**
Puissance dissipée maximale	256mA*1.8V ~ 0.5Watt	2*256mA*1.8V ~ 1Watt
Charges incidentes [courant x temp]	[13uA x 2ns] et [1.8mA x 0.4ns]	[13uA x 2ns] et [1.8mA x 0.4ns]
Hit rate maximum	16 cellules touchées pendant 400ns => **2.5MHz RATE**	**25 MHz**
Multiplicité	**8 pistes touchés par impact** **2 impacts possible => 16 cellules**	**2 piste/direction => 6 pistes** **1 seul impact** **=> 8 (+2 pour marge bruit)**
Taille donnée d'une adresse touché	**7-bit pour ROW + 6-bit pour COL**	**8-bit pour ROW + 7-bit pour COL** **(+ 2-bit augmentation taille x4)**
Horloge de lecture interne	40MHz par encodeur de priorité	40MHz /colonne
Taille des données	13-bit + Valid + Mrk	15-bit + Valid + Mrk
Horloge de lecture externe	40MHz sur 14-bit en parallèle 520 MBps	**8 liens 160MHz DDR** (double data rate) SLVS or **LVDS** ? 4.8GBps
Pitch (pas de quantification spacial)	5µm (hauteur d'un hexagone)	5µm
Nombre total d'hexagones	2 077 200 (~2 Million)	8 millions de pixels

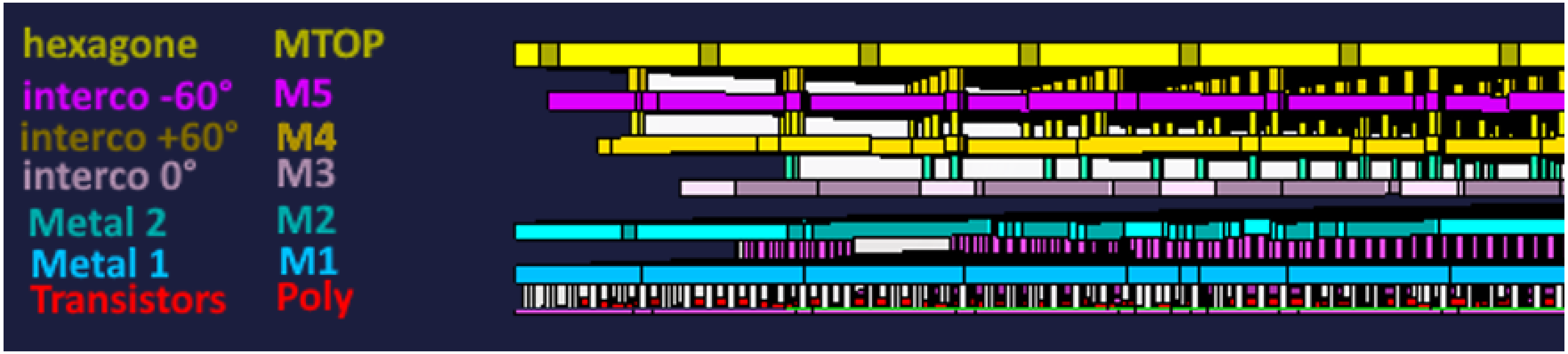


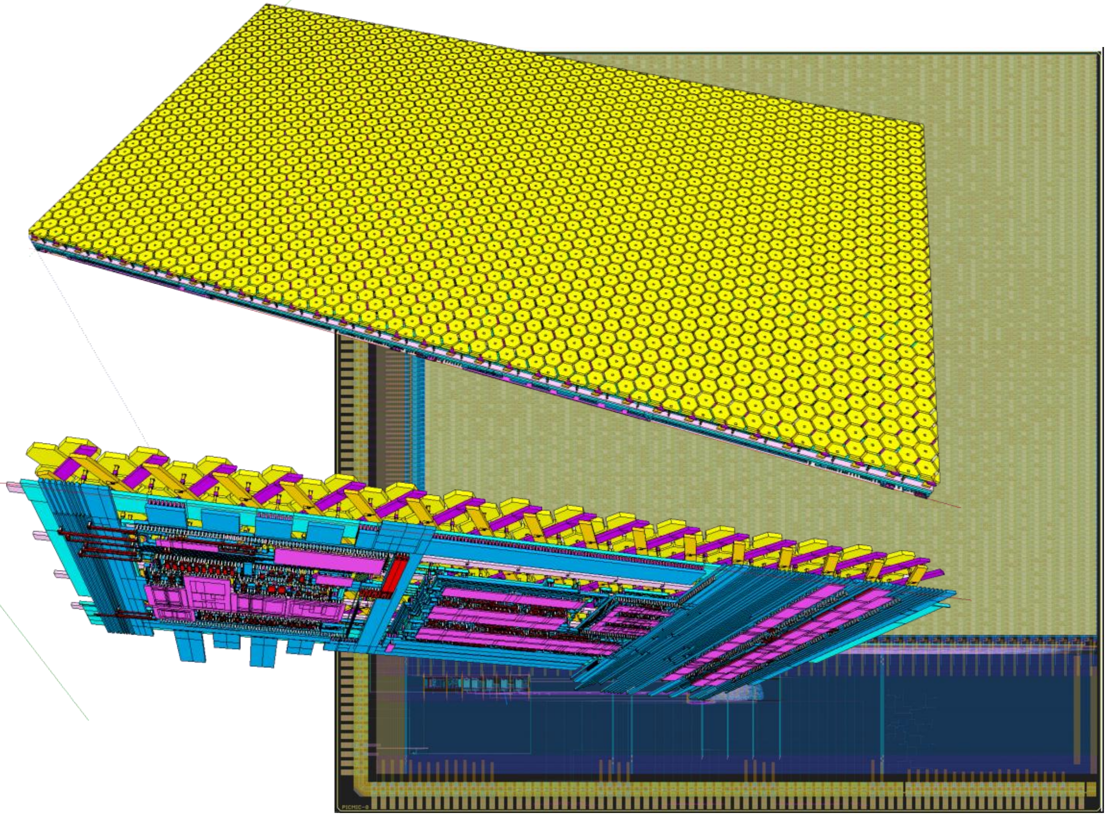
3 directions * 852 lines,
each line connects a comparator

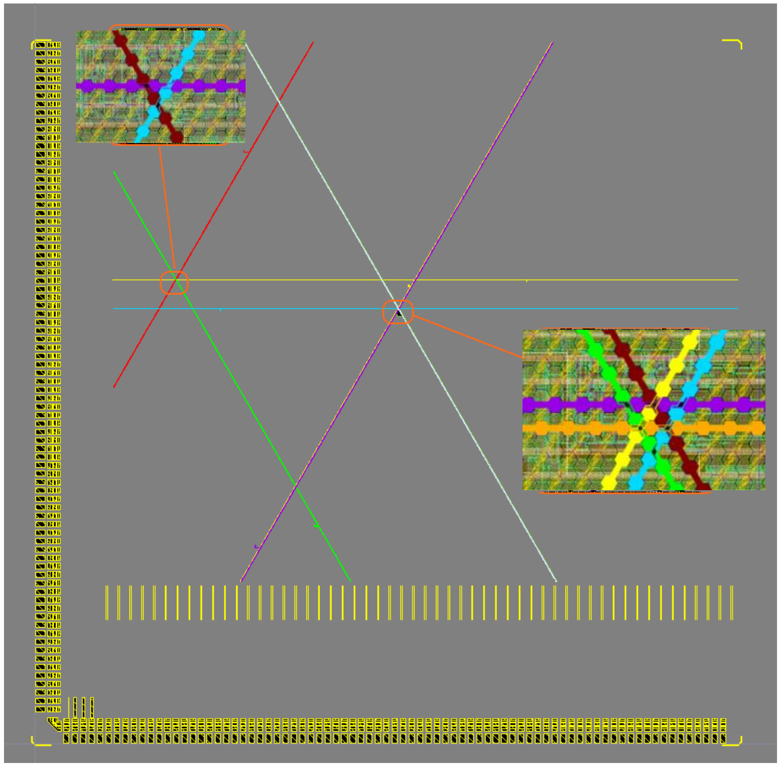




Depending on the algorithm, the readout-cell is somewhere in-between the line
Depending on the position of the shower impact, the discriminator could be at strong opposite

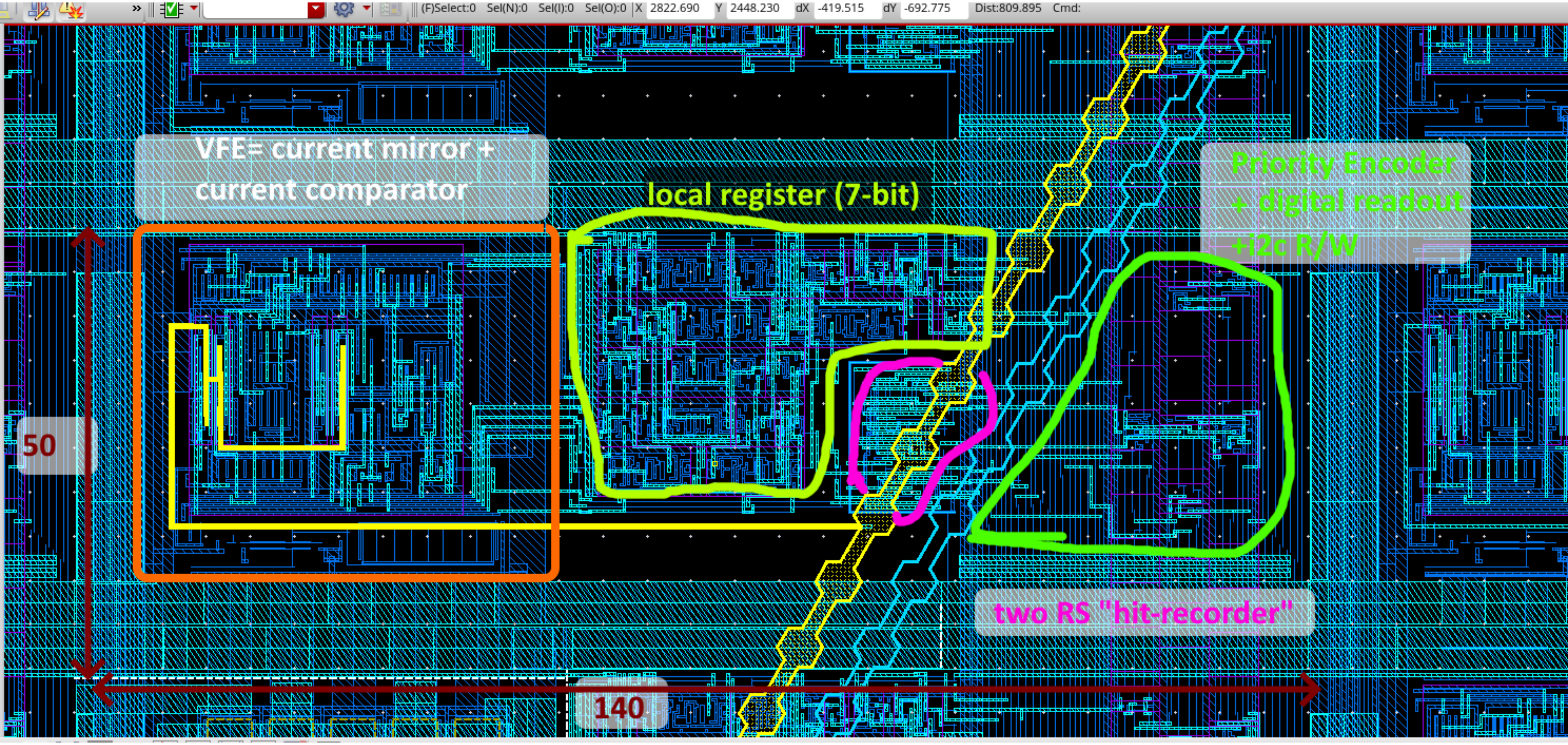

hexagone MTOP
interco -60° M5
interco +60° M4
interco 0° M3
Metal 2 M2
Metal 1 M1
Transistors Poly



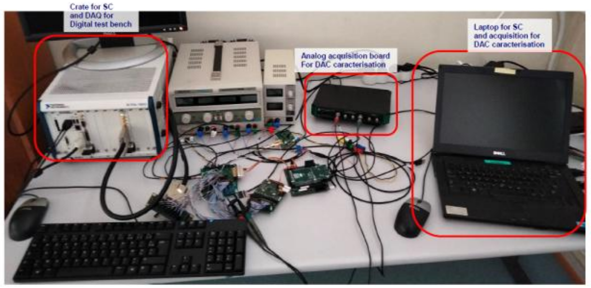


Layout of readout cell

Layout of readout-cell with M1 and M2: 140u x 50u

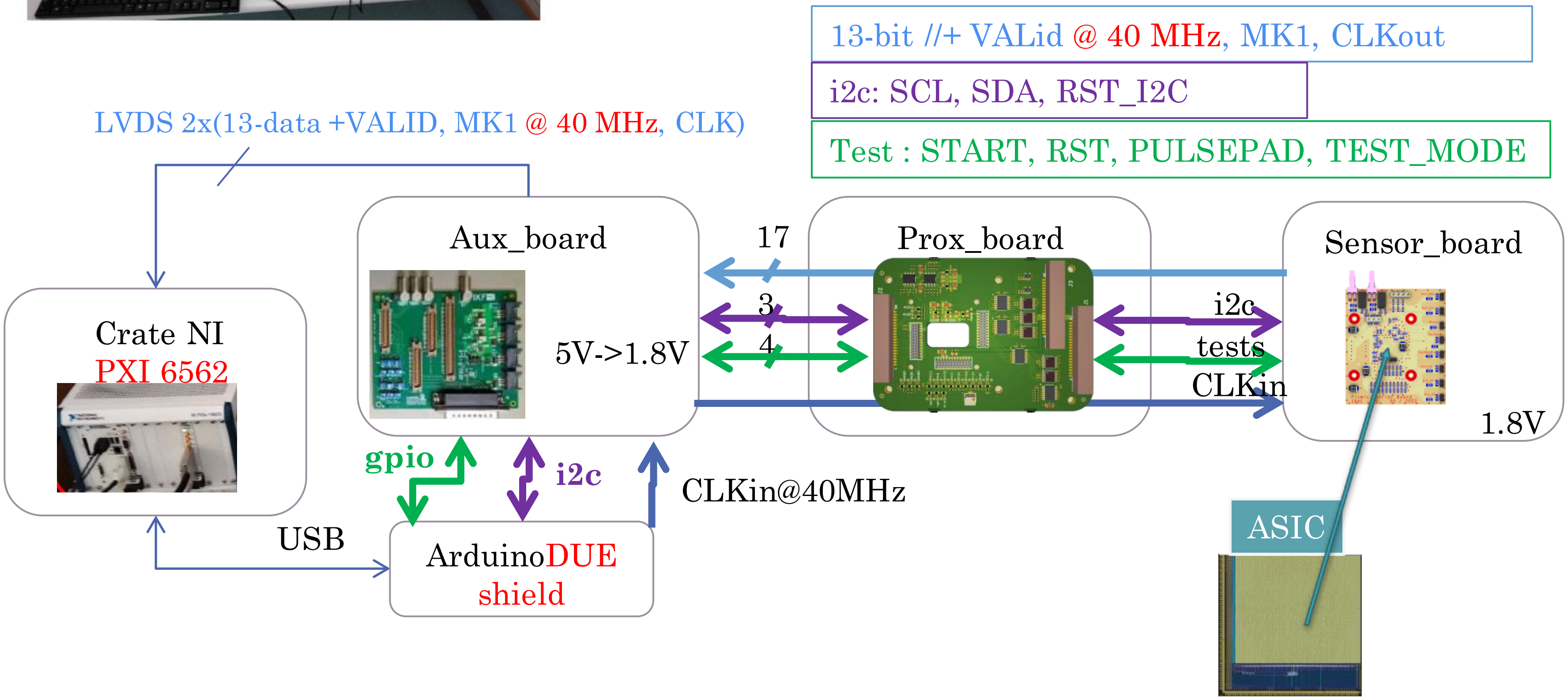


PICMIC0 DAQ

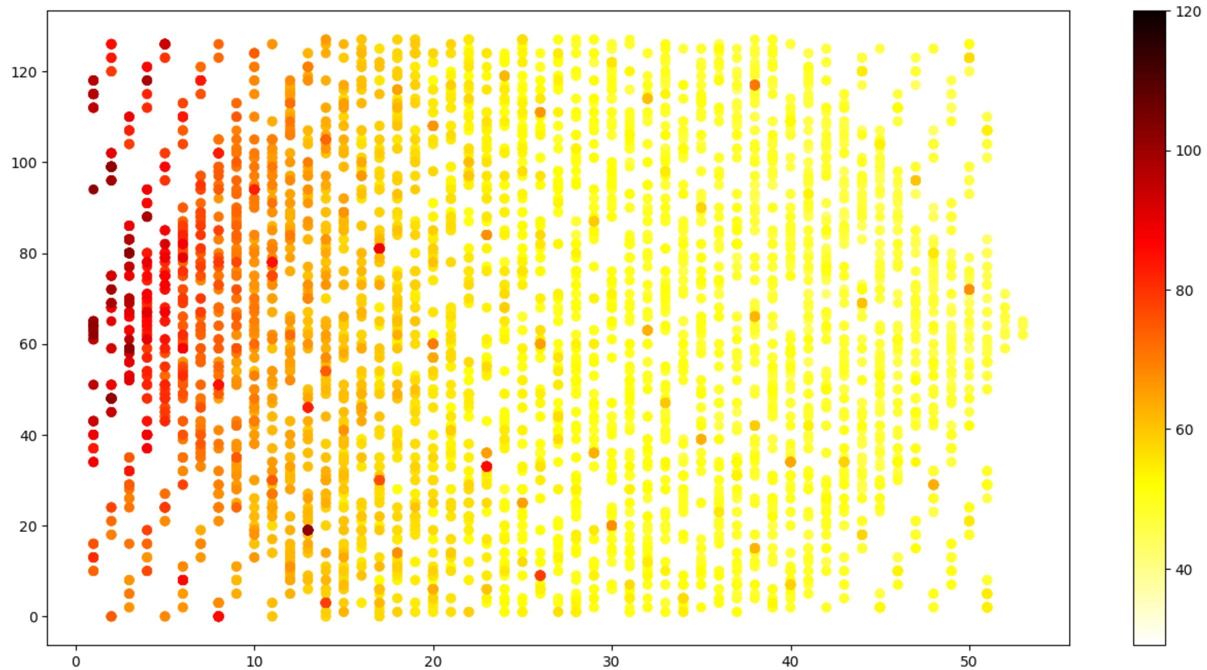


Test bench HW developped by IPHC

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



Unwanted effect observed : threshold spread in the current comparator reference, due to IR-drop in the matrice **before** calibration.
Threshold varies from 40µA to 120µA



Also 38 channel are noisy due to coupling between the memory Flush signal in Metal 2 with a few horizontal Metal 3 lines