First results of the PICosecond subMICrometer (PICMIC) concept

I.Laktineh

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ILM: A. Ayari

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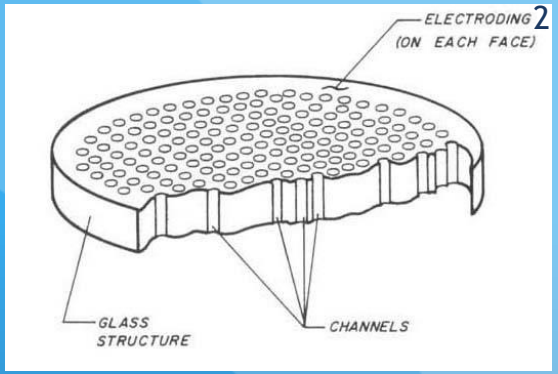
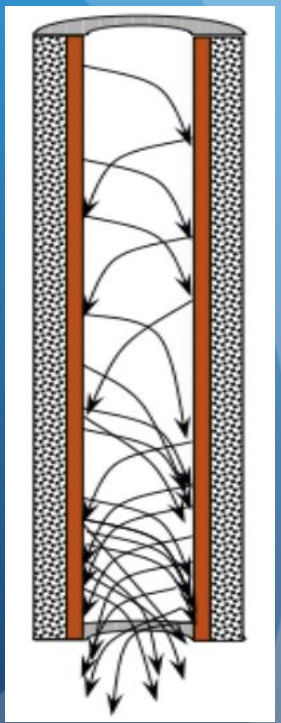
Micro Channel Plate (MCP)



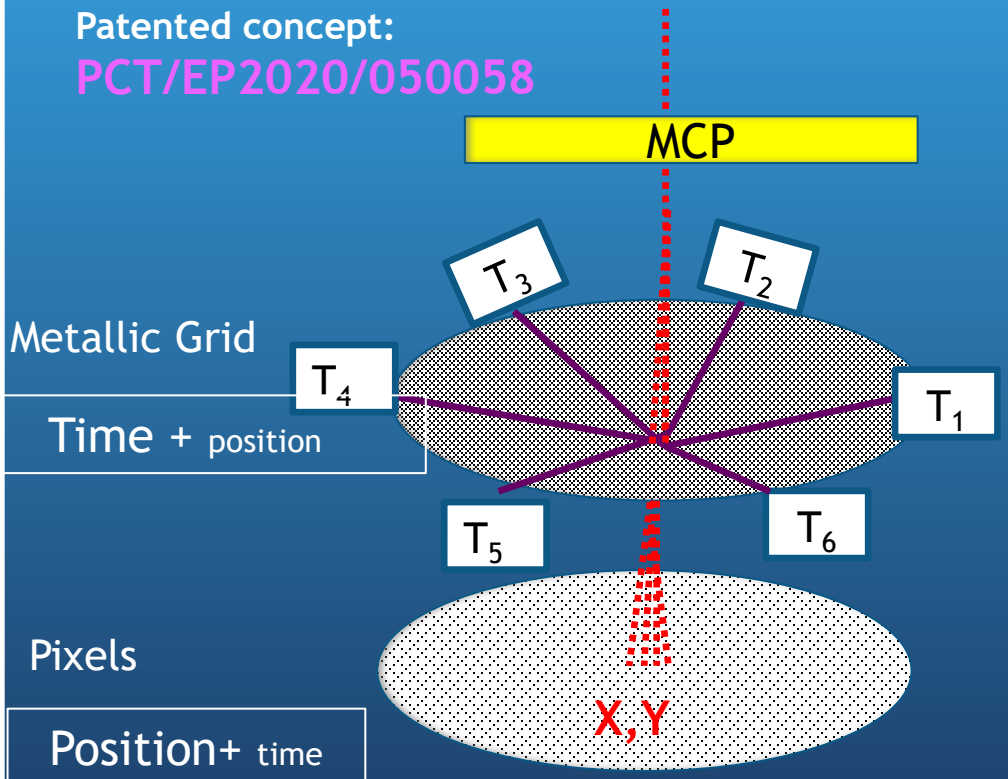
- MCP is as for now is one of the best **timing** devices with a few picoseconds of resolution.
- MCP has an excellent intrinsic spatial resolution since the avalanche produced by the incoming particle is constrained to one of the glass tube whose diameter can ban as small as 2-3 μm
- **MCP are often used for their timing while their spatial resolution is not appropriately exploited.**



To fully exploit MCP we propose the following scheme:

- A transparent grid placed downstream the MCPs and read out by sensors with excellent time resolution. Followed by:
- A detection matrix with micrometric pixels to measure with great precision the position of the avalanche while requiring limited number of electronics channels.

Patented concept:
PCT/EP2020/050058



Concept description

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

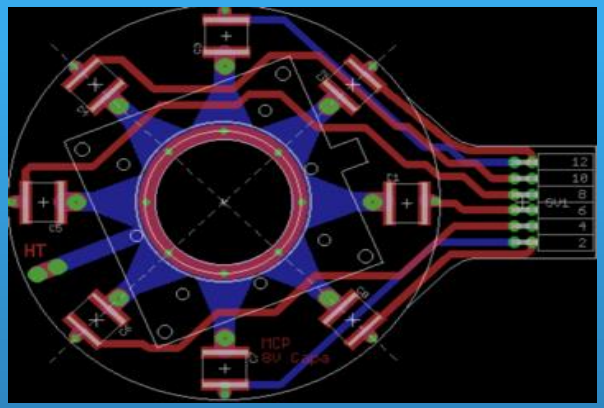
1- Measure X,Y, from the fired woven strips b crossing them geometrically

2- Measure T_i (from time sensors)

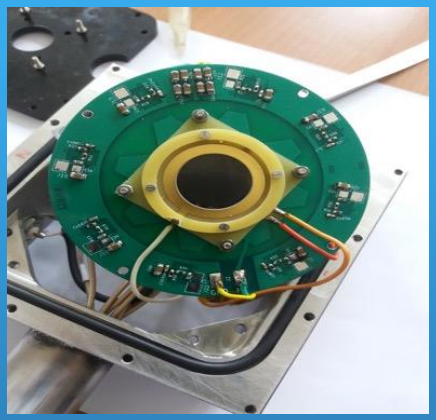
3-Substract time propagation using speed propagation and X-Y)
4- average on the (T_i-T_i(propag))

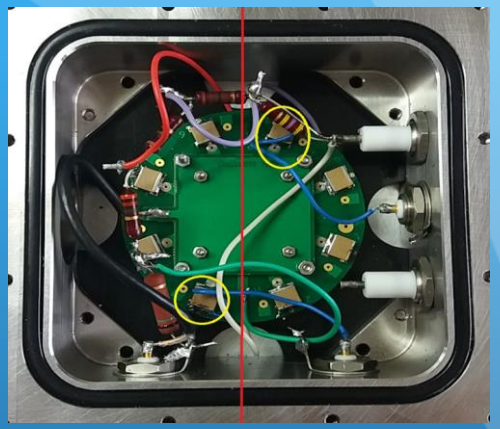
$$T_{abs} = \frac{\sum_0^N T_i - T_{i-propag}}{N}$$

Time Measurement



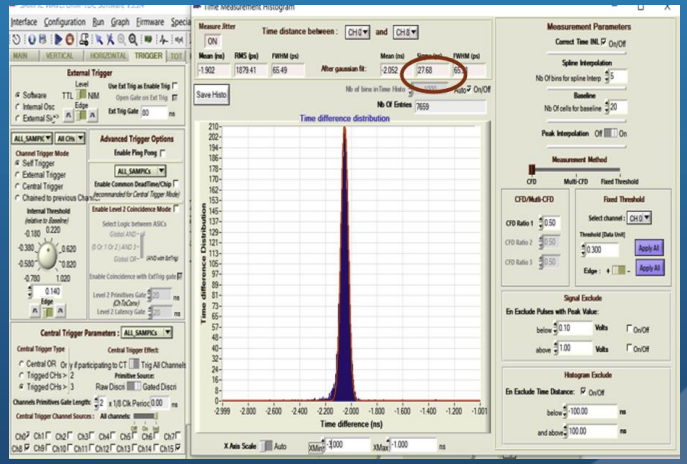
8-point PCB for the time measurement.
PCB to be in contact with the grid





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

SAMPIC: TDC ASIC allowing
to reach 3 ps time resolution

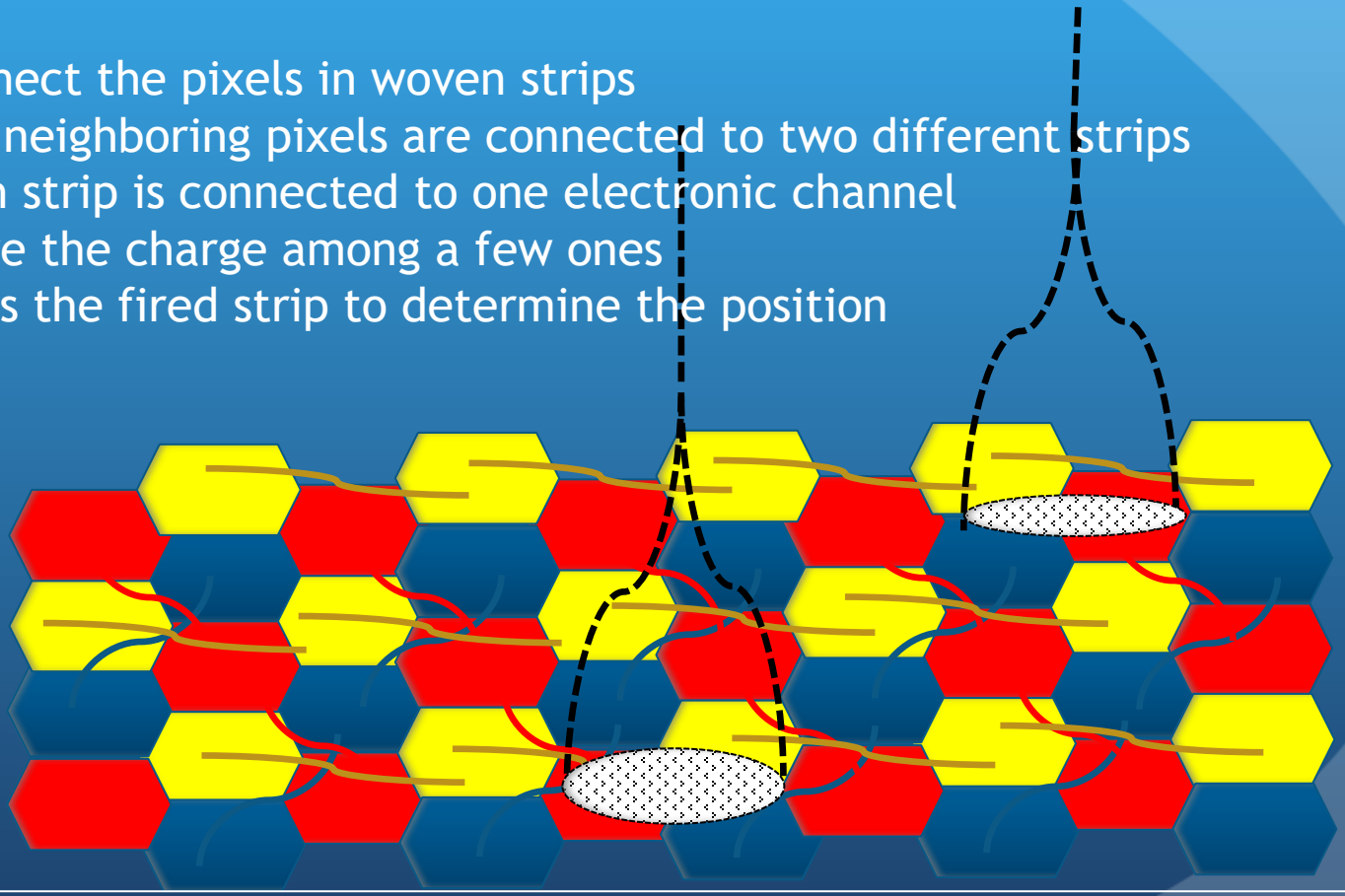


Time resolution of arrival time of two channels is of 30 ps → 10 ps by exploiting 8 channels

Position measurement

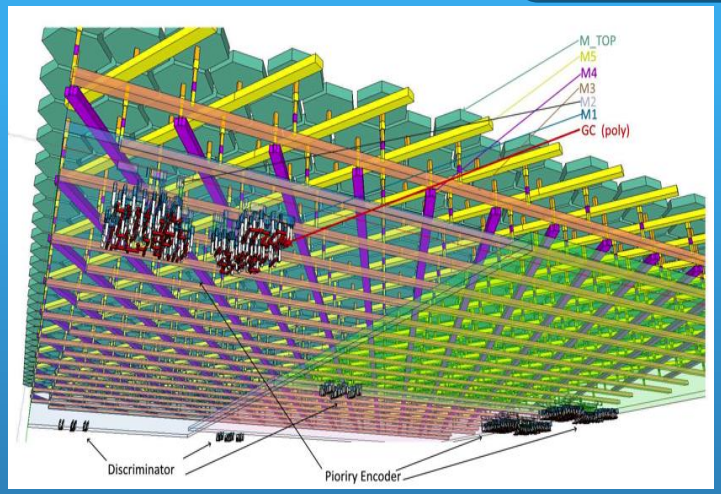
To reach few microns resolution with a limited number of electronic channels, a new concept was developed, successfully **tested** and **patented**.

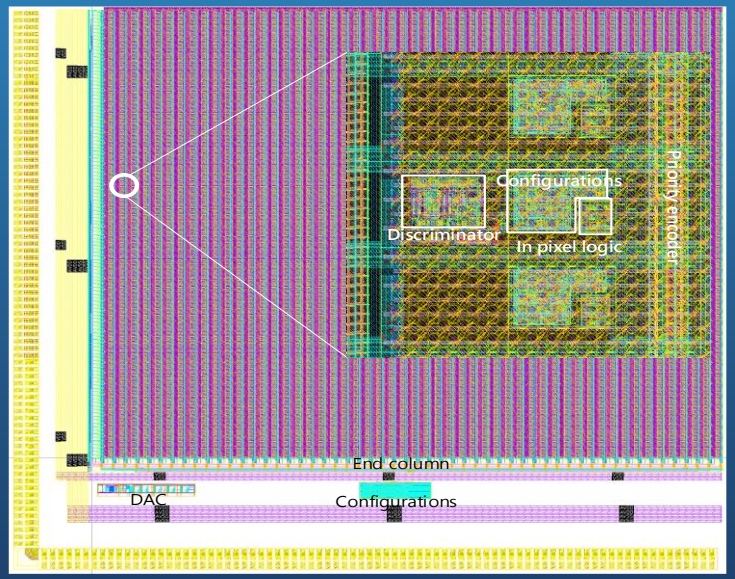
- Connect the pixels in woven strips
- Two neighboring pixels are connected to two different strips
- Each strip is connected to one electronic channel
- Share the charge among a few ones
- Cross the fired strip to determine the position



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

Position Measurement

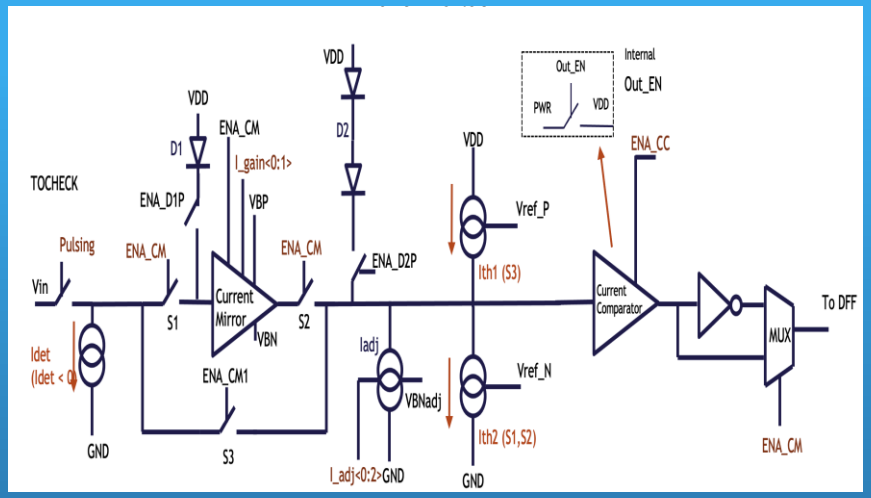


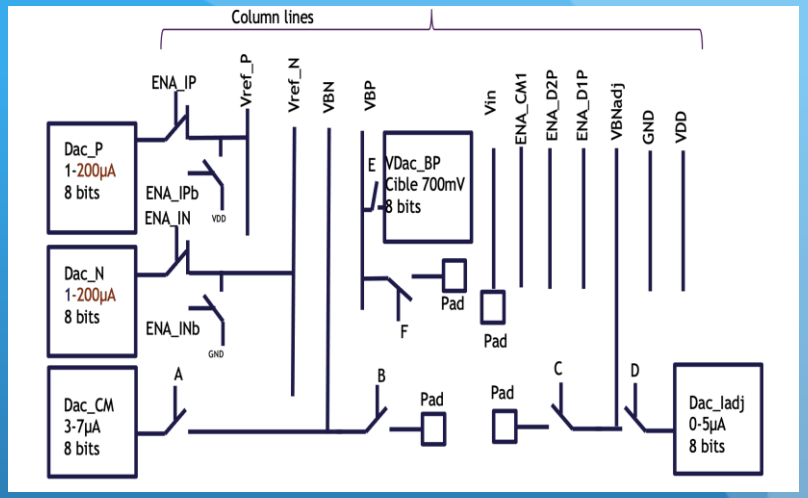


Although no silicon sensor is used, the CMOS wafer technology was used.
Pixels, the interconnections as well as the readout electronics are conceived in TJ 180 nm (6 metal layers) technology.

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	I2C
Max data rate (1Mhz hit rate)	390Mbps

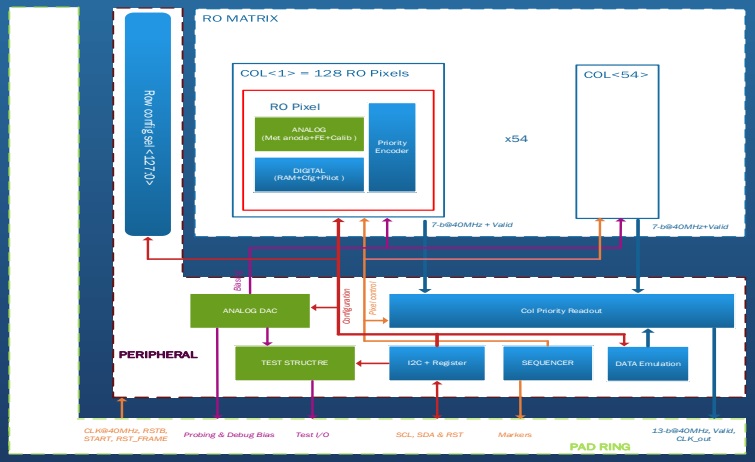
PICMIC pixel electronics Layout





Current conveyer 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.

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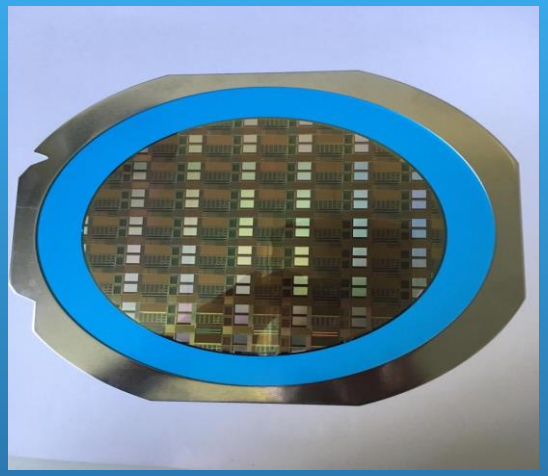
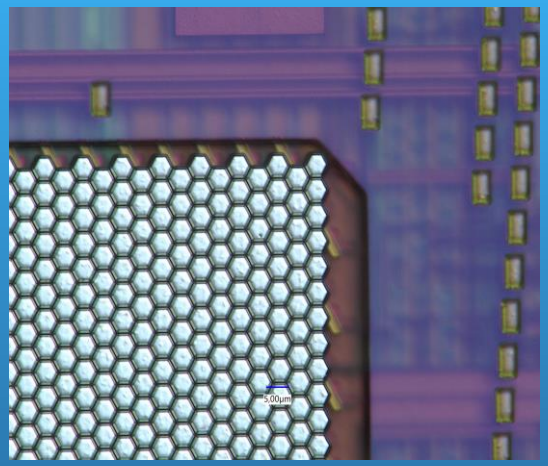
Pixel chip

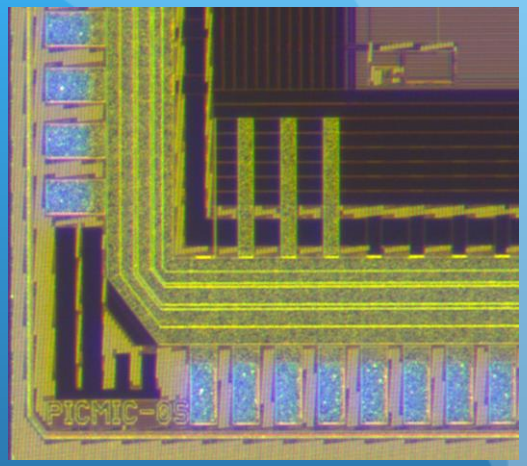
The chip was submitted in November 2021 (TowerJazz) and received on July 2022



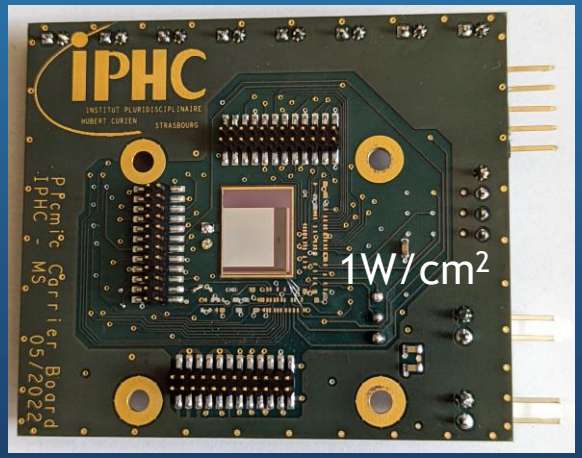
TJ wafer



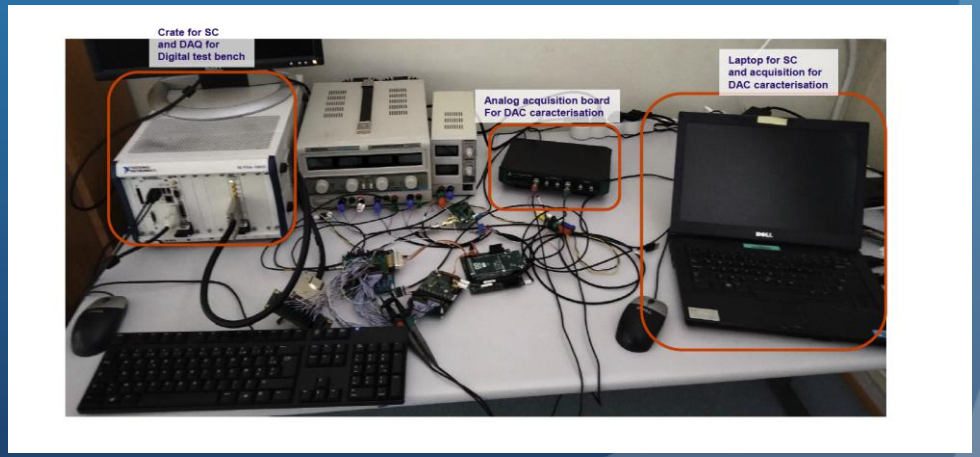
Hexagonal pixels



External links



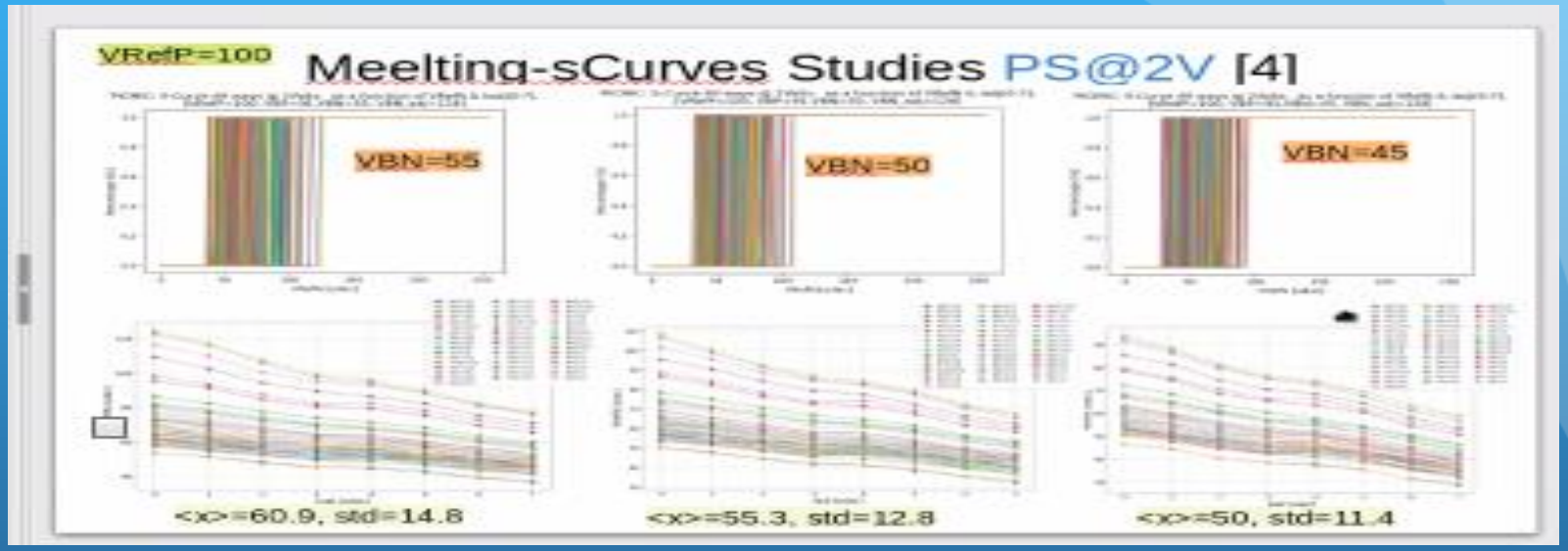
First mezzanine

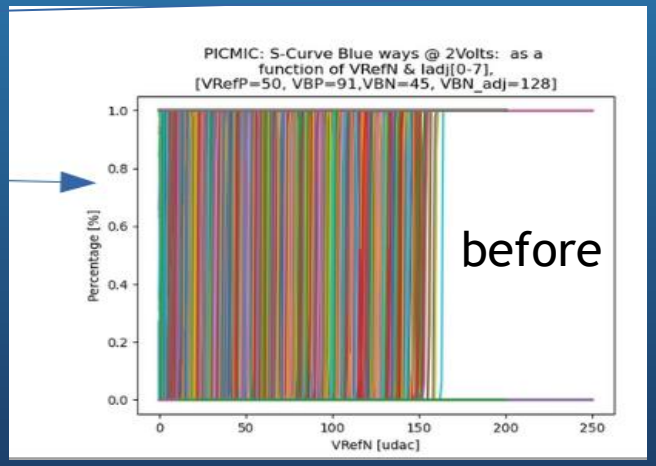


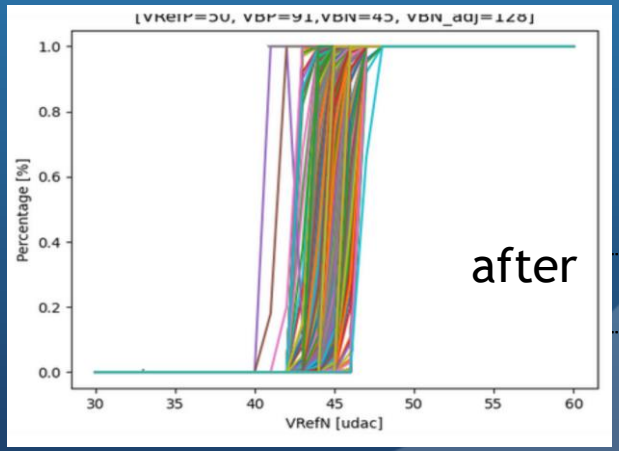
First tests

Pedestal threshold calibrations

A scan of all the DAC values was performed to find the best operational point







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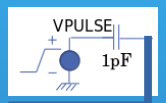
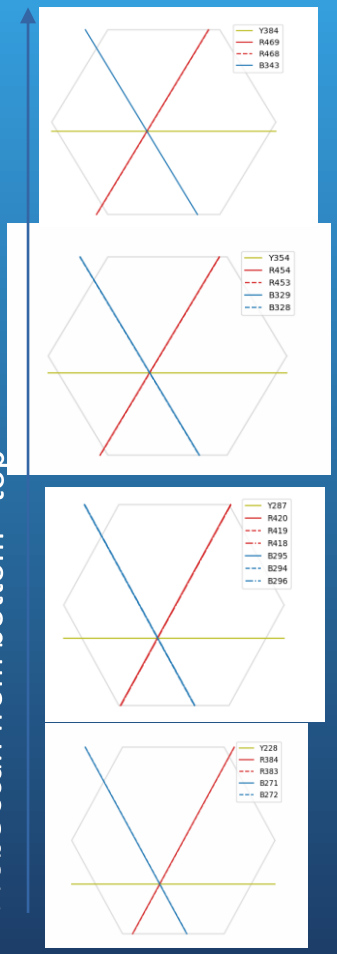
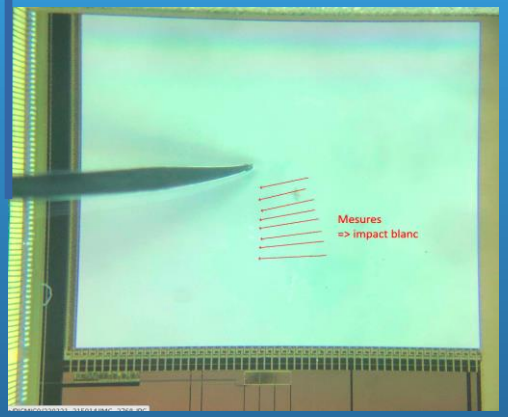
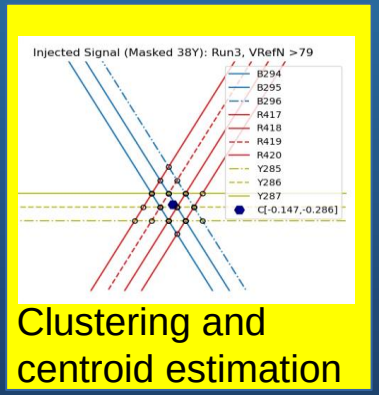
Test with direct injection of charges using probes

One-probe injection





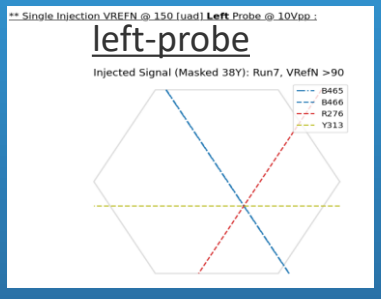


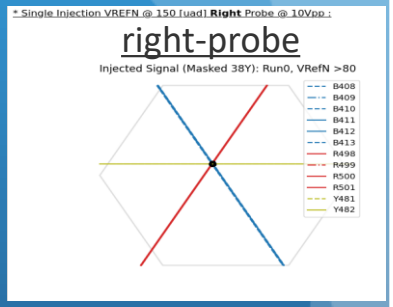


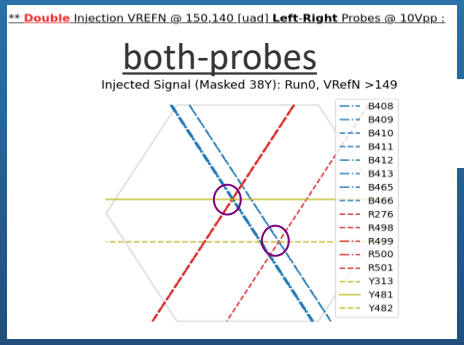
Clustering and centroid estimation

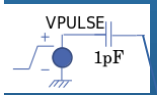
Probe scan from bottom - top

Two-probe injection







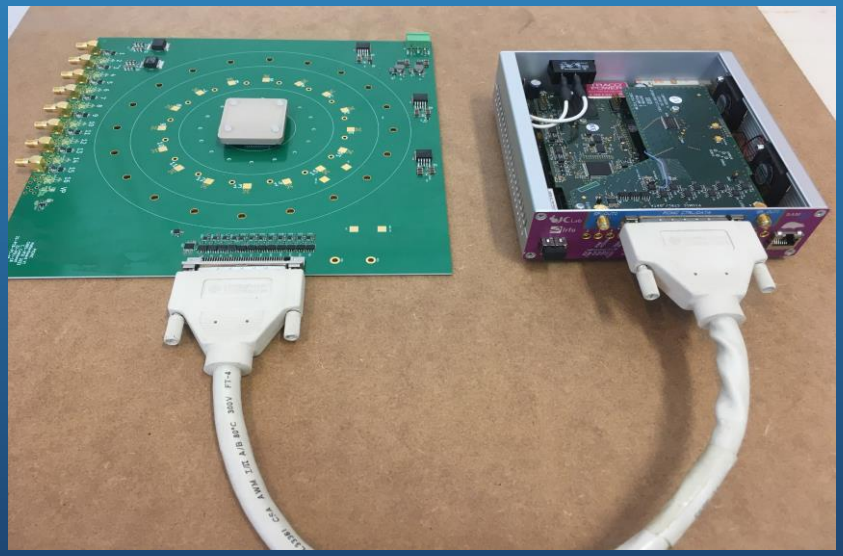


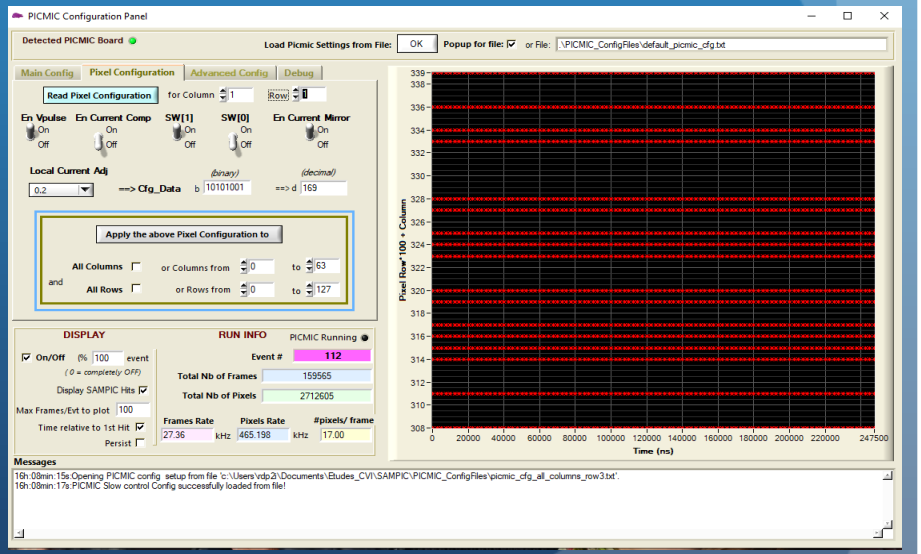
Towards the first PICMIC demonstrator

With both time and position sensors tested, a DAQ board was conceived to

1) Distribute the same clock (40 MHz) to both the timing and position chips
2) Collect data from both and associate them.

The DAQ board was placed within the SAMPIC module.



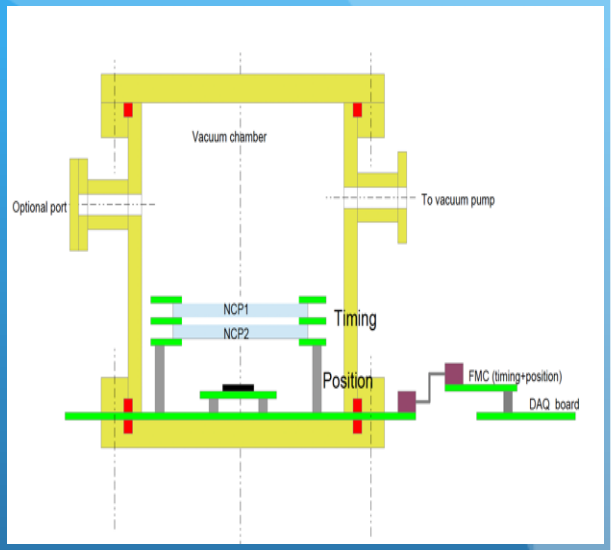


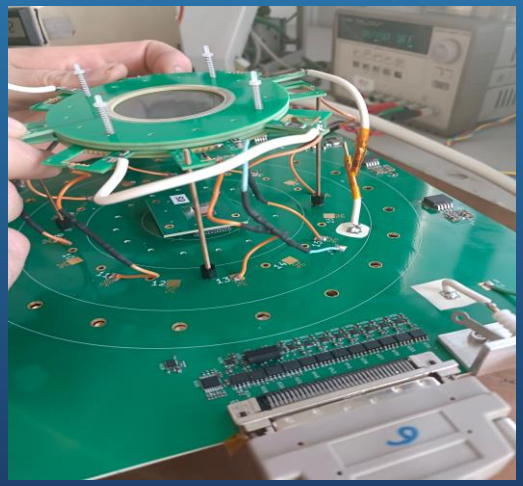
Towards the first PICMIC demonstrator

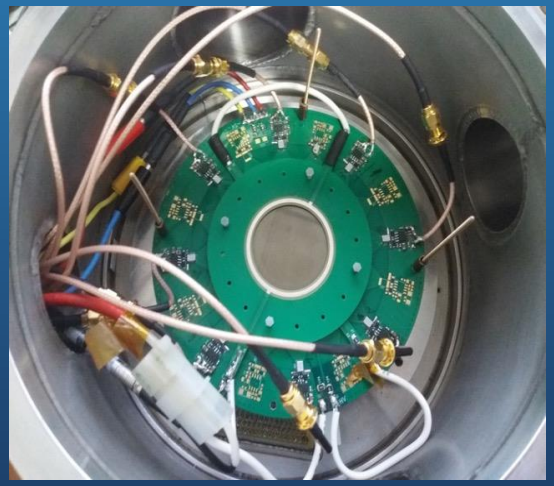
The first prototype including:

- Two 5-cm diameter MCP
- A board hosting 16 timing sensors (only 8 were cabled)
- A mezzanine hosting the pixel sensors
- A Master board

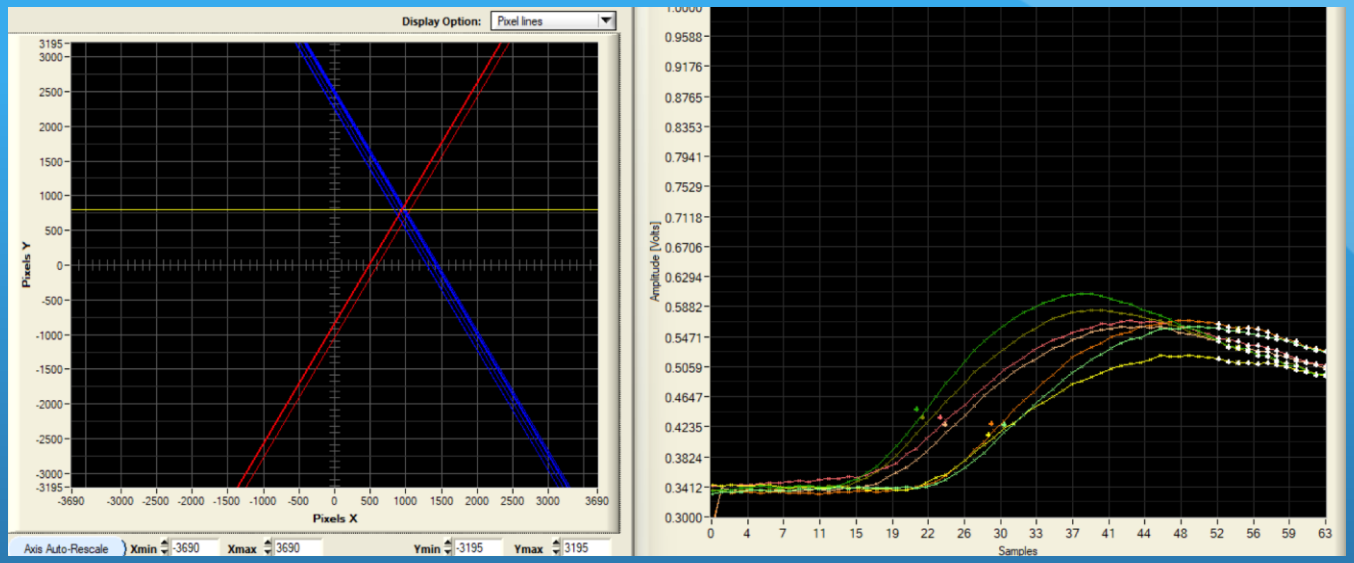
All are placed within a vacuum system (<10e-5 mB)

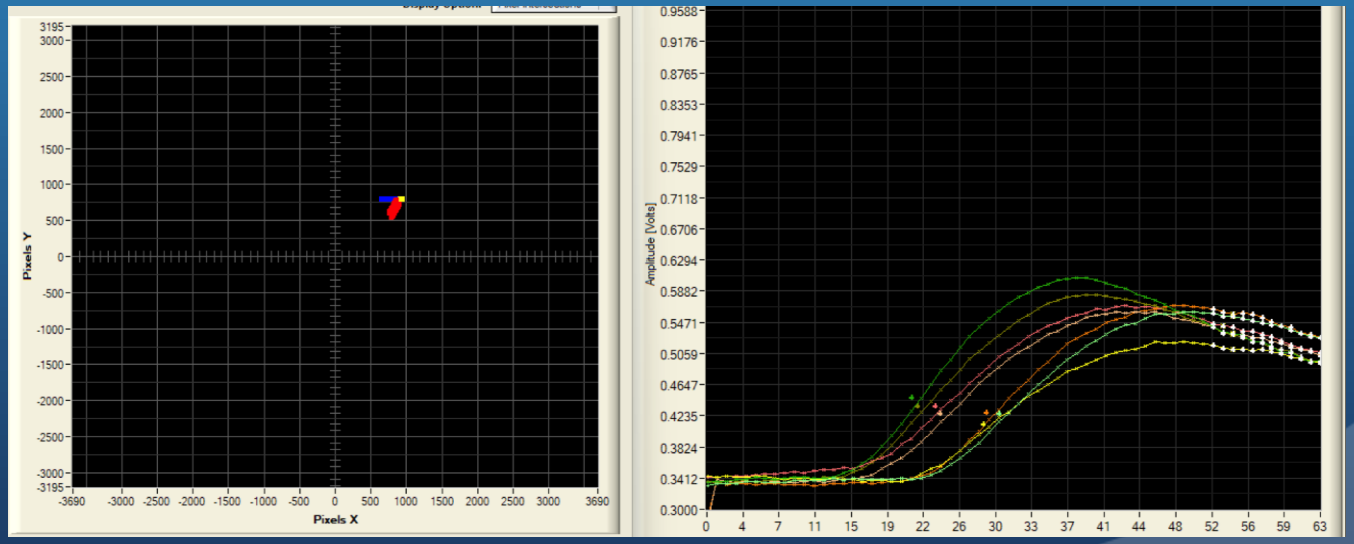






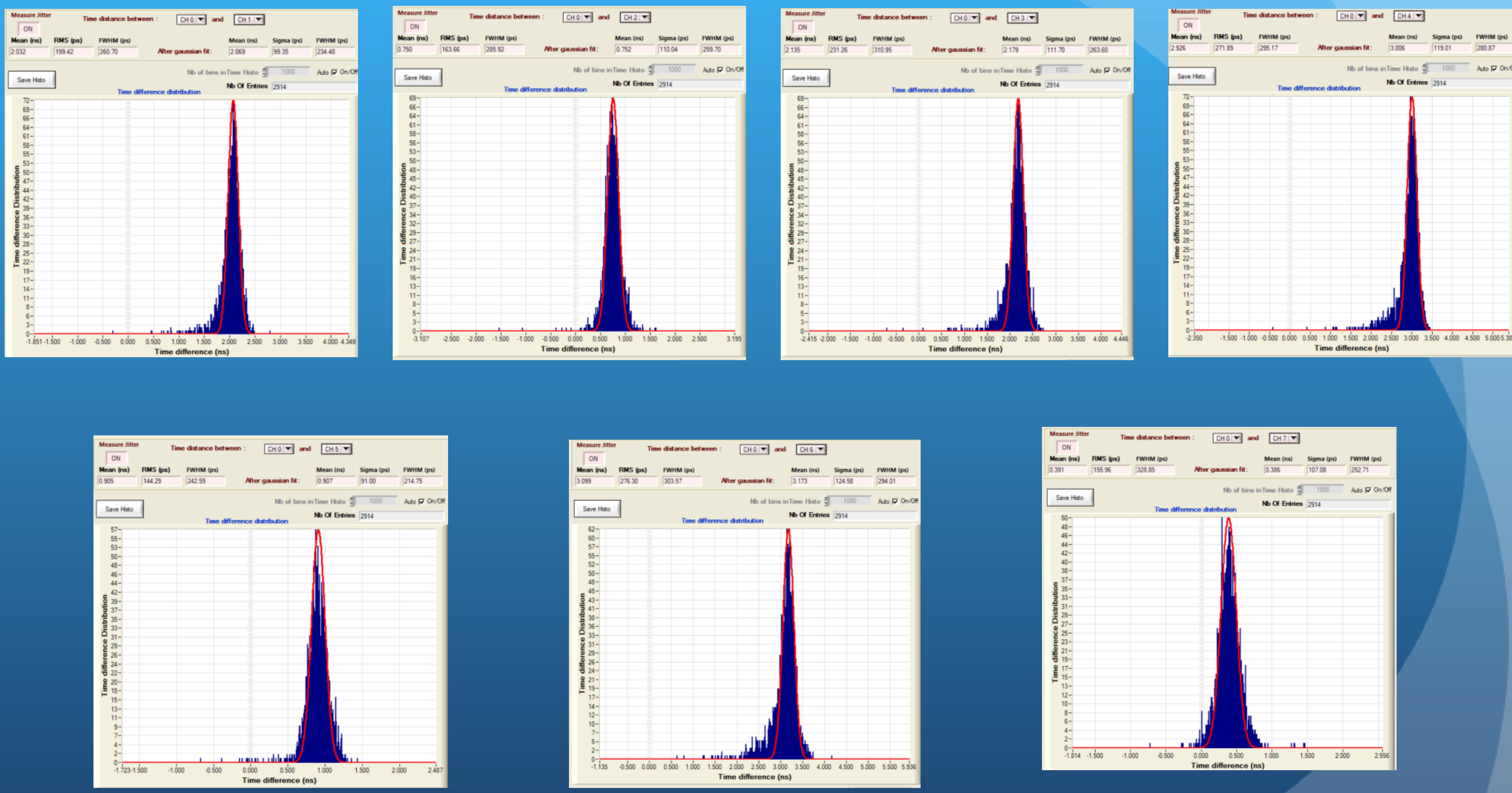
The whole system was tested by using collimated α and γ sources





First results

Histograms of arrival time difference of Ch1,Ch2, Ch3, Ch4, Ch5, Ch6,Ch7 and Ch0 (700 V/MCP)



σ (T_i -T_j) is 100-120 ps → σ_{abs} is expected around 25-30 ps

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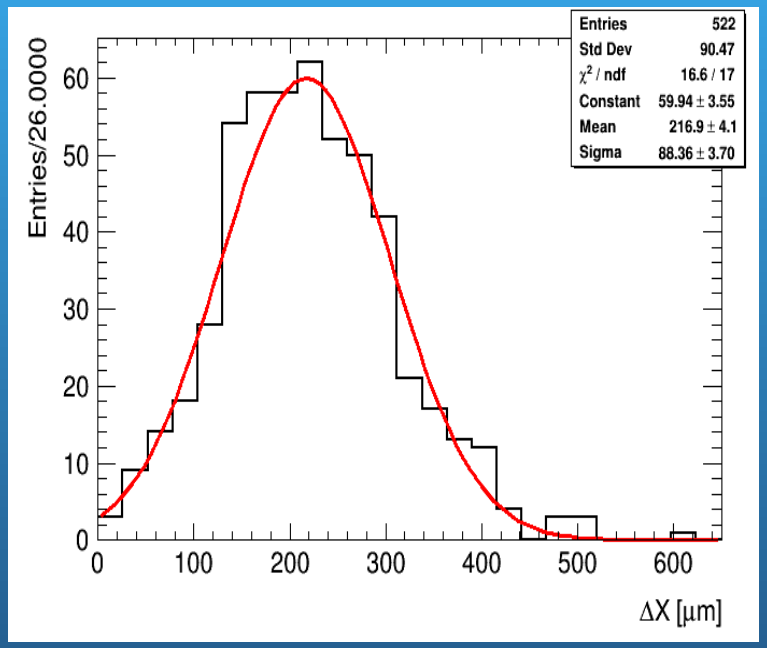
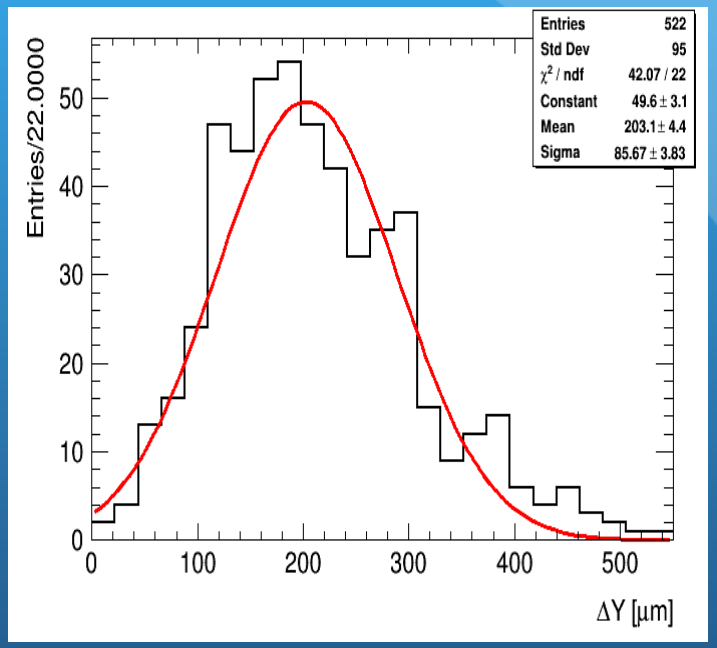
First results

Average span in X and Y of pixel clusters obtained with an α source



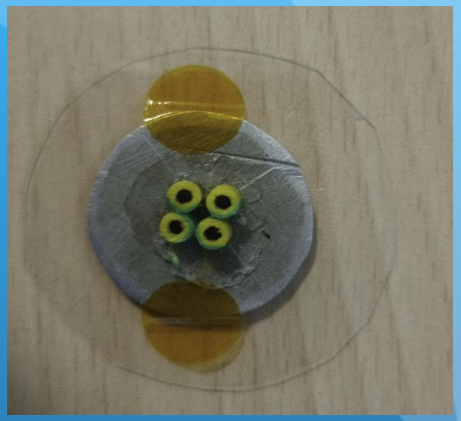


X_{max}-X_{min}

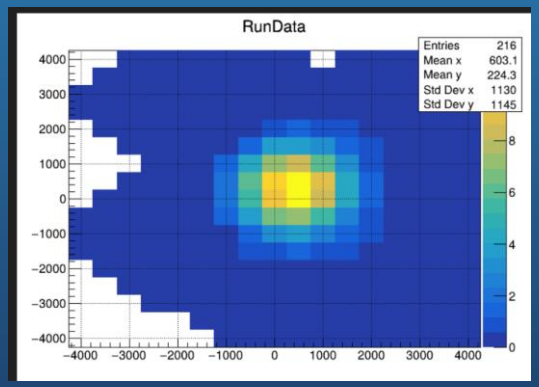
Y_{max}-Y_{min}

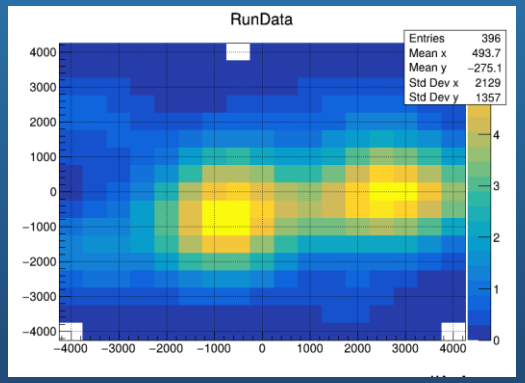
Spatial resolution < 100 μm

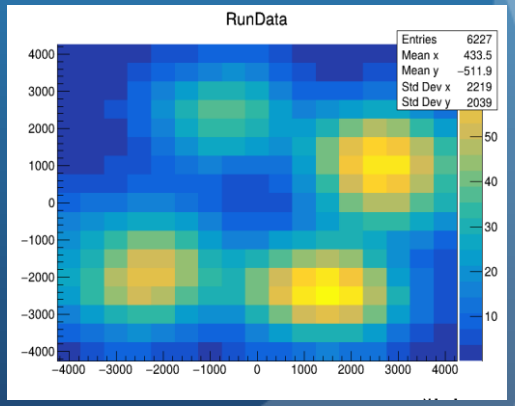
The whole system was tested by using alpha and gamma sources



1 mm diameter hole







Next step

PICMIC will be soon tested with a channeltron producing single electrons of energy up to 30 keV in a MEB to have independent time and resolution measurement

Next step: Time Measurement

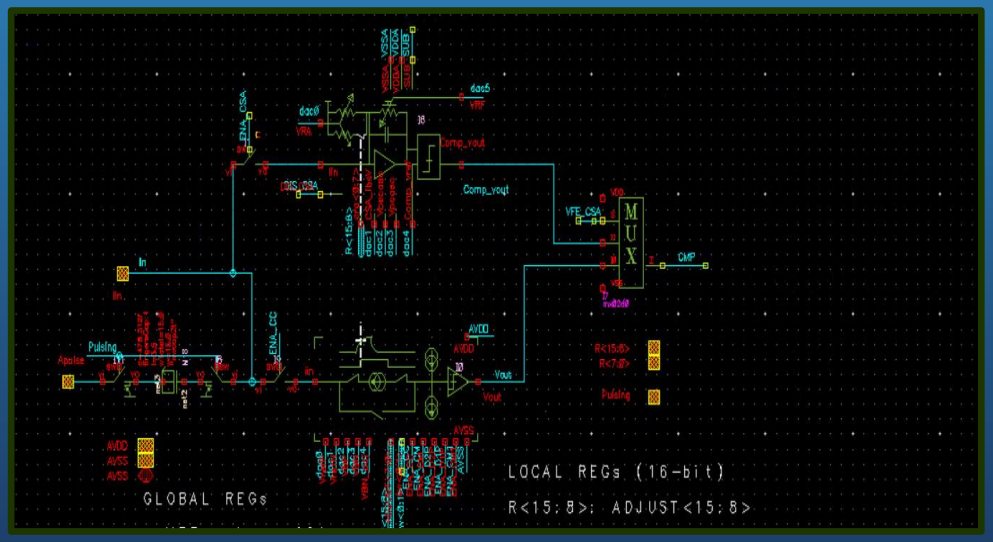
SAMPIC is an excellent tool but has a dead time of about 1 µs.
Another timing measurement having a TDC with a negligible dead time is needed to use PICMIC in higher rate modes.

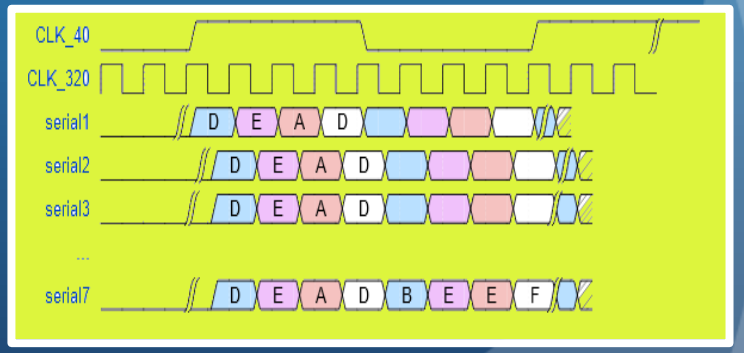
A board integrating a low-jitter timing preamplifier and discriminator (LIROC-OMEGA) as well as a precise TDC (picoTDC-CERN) was conceived.
The board will use the GBTX developed by the CERN to communicate with the DAQ system.

Next step: Spatial Measurement

The PICMIC0 chip was the first attempt to demonstrate the concept. We need to improve on several features:

- Better calibration possibilities (8-bit DAC) to get better uniformity
- 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.
- Higher acquisition rate (1 MHz → 10-30 MHz)





PICMIc1 is ready for submission

I. Laktineh

Next step: Acquisition

IDROGEN board that was developed within the DAQGEN based on White Rabbit protocol will be used.

To be able to exploit the IDROGEN board we :

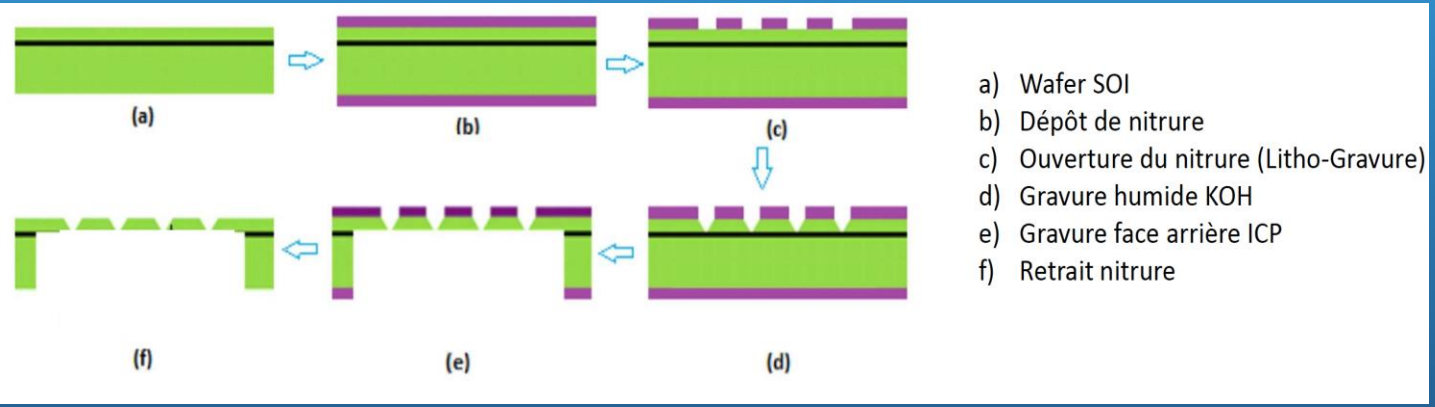
- **developed appropriate interface/mezzanine boards** between the IDROGEN and the timing and position boards.
- developed **an appropriate firmware**

PICMIC for photodetection

We are developing a highly granular reflective photocathode.
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.

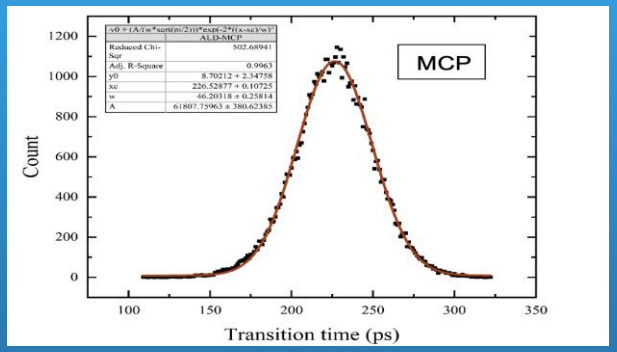


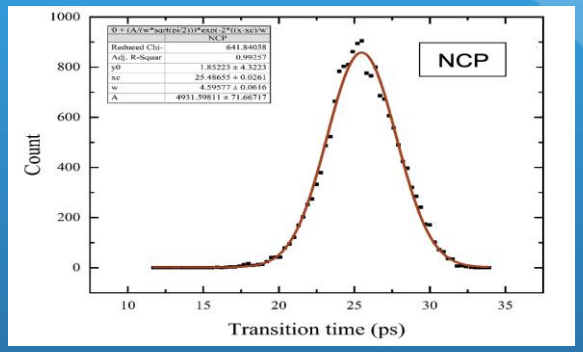
Efforts are now to produce large surface

I. Laktineh

NCP

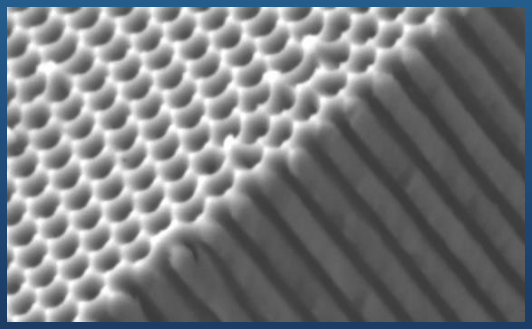
A new kind of MCP that we call NanoChanel Plate (NCP) is being developed.
It aims at producing structures with nanoholes that could be coated with emissive and resistive materials.

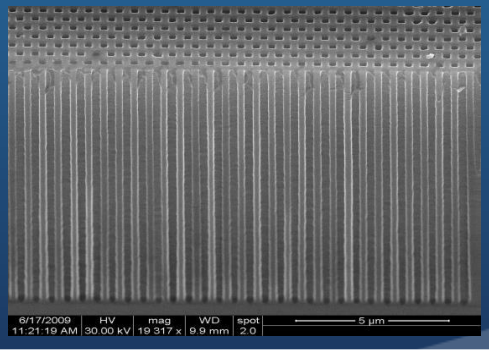


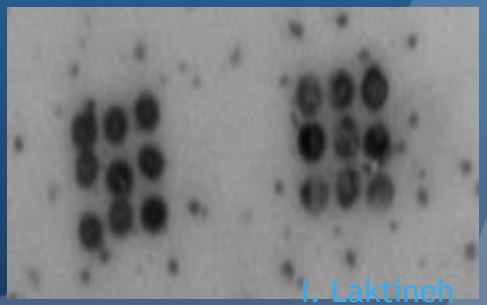


Three technologies are followed:

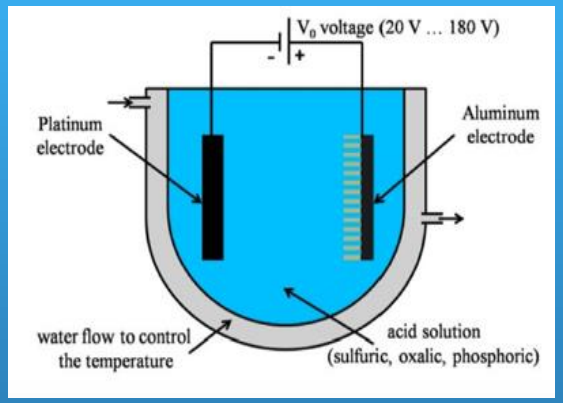
- Anodized Aluminium Oxide AAO
- Silicon electrochemical etching
- Femto-laser digging

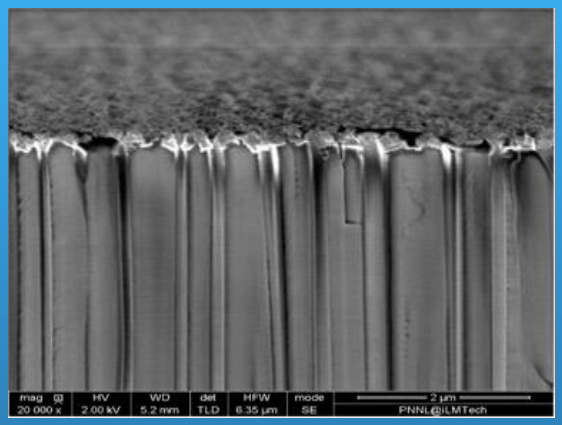


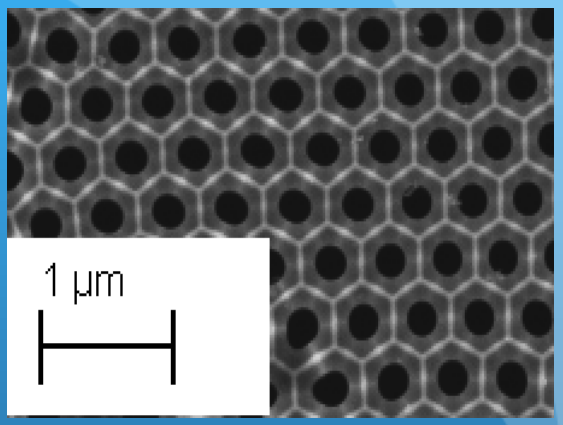


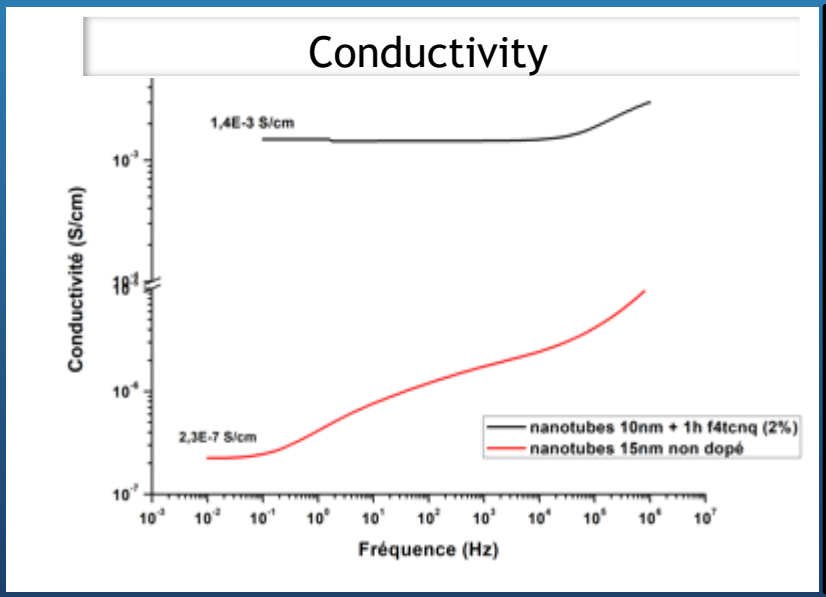


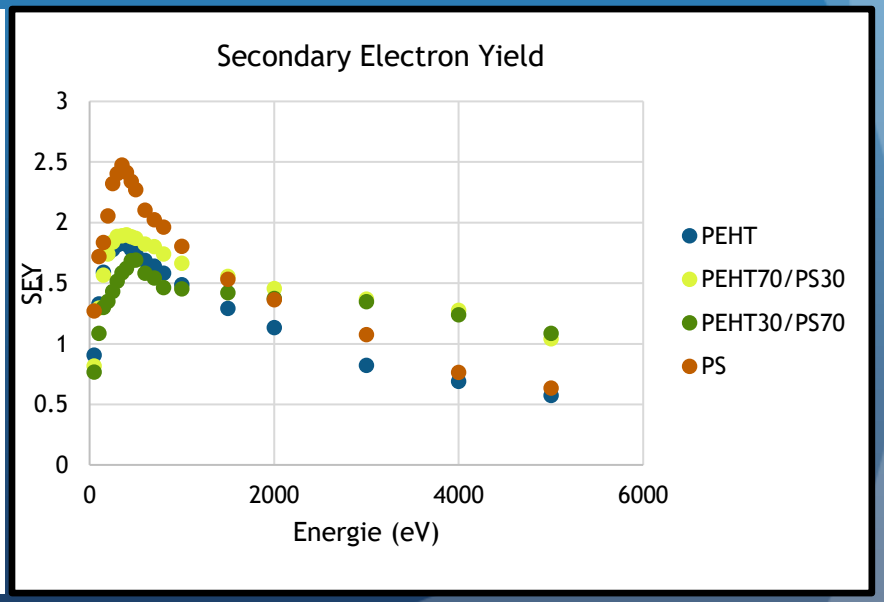
NCP-AAO


V_0 voltage (20 V … 180 V)
-
+
Platinum electrode
Aluminum electrode
water flow to control the temperature
acid solution (sulfuric, oxalic, phosphoric)




1 µm


Conductivity
1,4E-3 S/cm
2,3E-7 S/cm
Conductivité (S/cm)
Fréquence (Hz)
nanotubes 10nm + 1h f4tcnq (2%)
nanotubes 15nm non dopé


Secondary Electron Yield
SEY
Energie (eV)
PEHT
PEHT70/PS30
PEHT30/PS70
PS

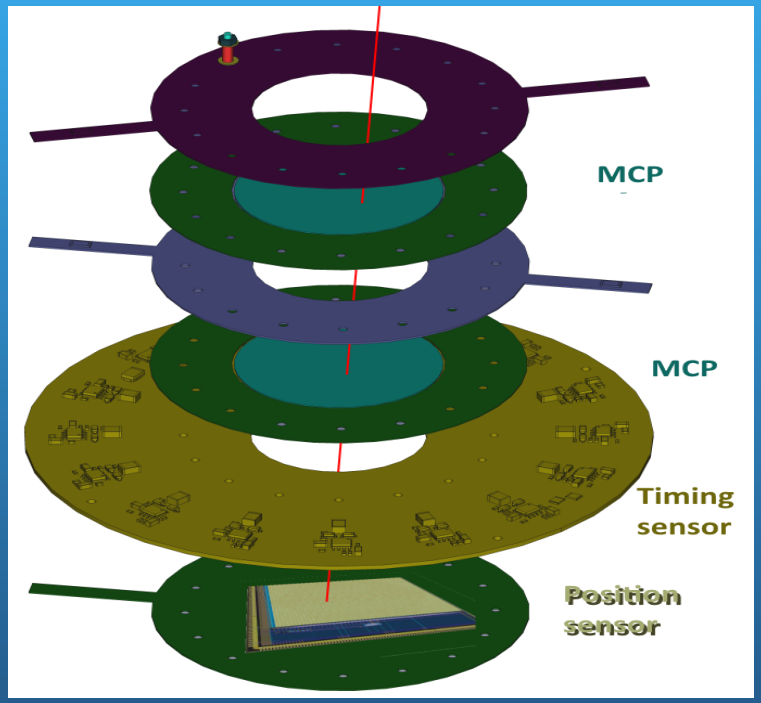
Summary

- The PICMIC concept that allows to simultaneously measure the time and position of MCP is validated
- Optimization is ongoing and independent resolution measurements

- High-rate capability with large surface device will be soon produced
- New high granular reflective photocathode is being developed and will be soon tested on MCP
- A new generation of MCP called NCP with the aim to reach 1 ps and sub-micrometer resolutions are being developed

These activities are part of the new DRD4 Collaboration within WP4.2

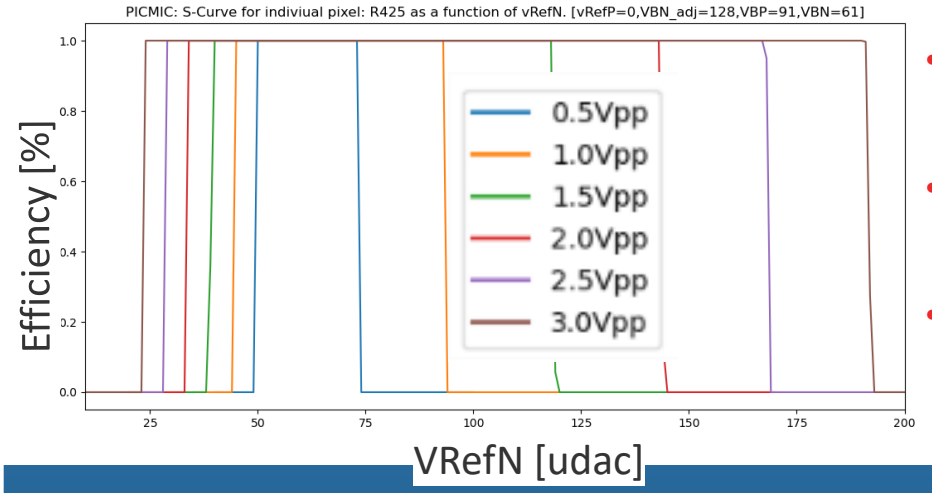
The structure of a PICMIC device



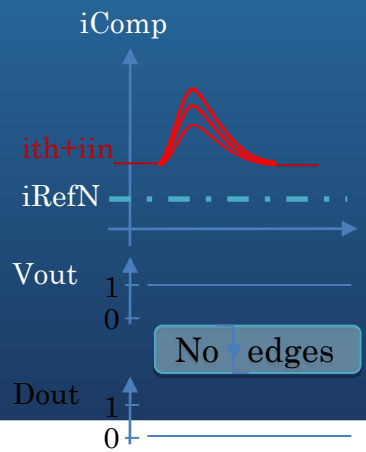
Injections Studies

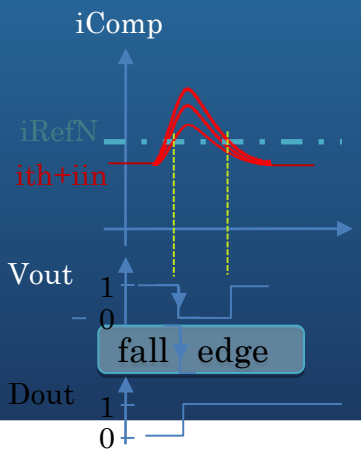
(1/2)

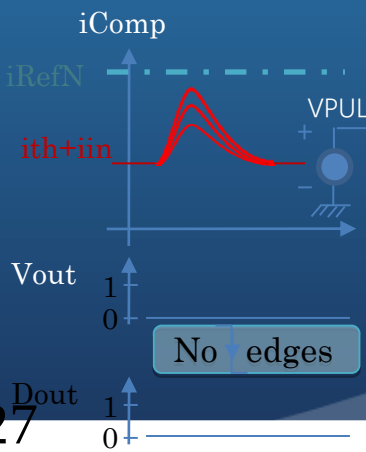
PICMIC allows external signal injection trough the (PAD):
- **R424**[R68,C28],**R425**[R103,C35] and **R426**[R6,C15].
- * it also allows to excite whole columns in the channel matrix (no shown in above layouts).

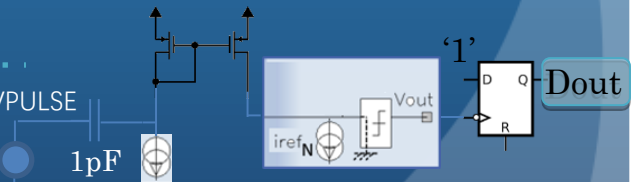


- Voltage injection through external 1pF, then scan of the threshold of Current Comparator.
- Below the current threshold, the falling edge sensitive does not trig.
- The signal is recorded on falling edge, so above a certain value of iRefN added to threshold current, the comparator does not trig anymore-→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



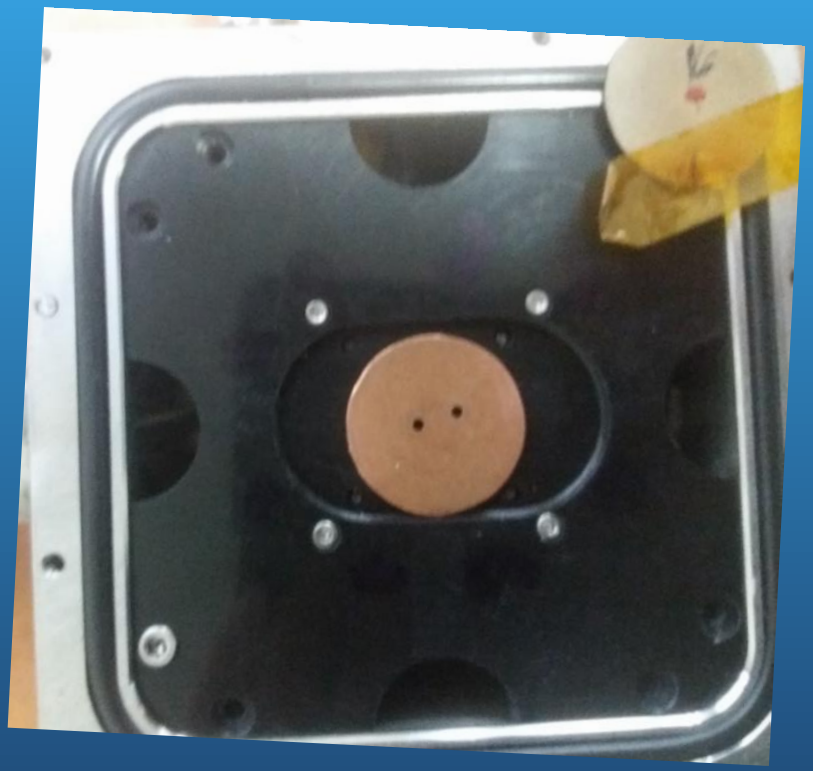


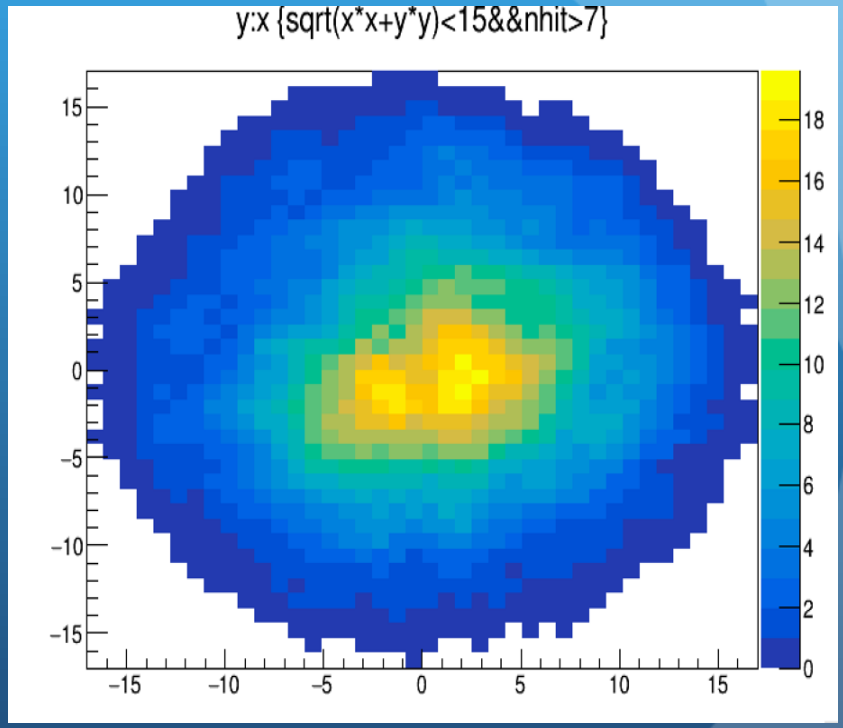




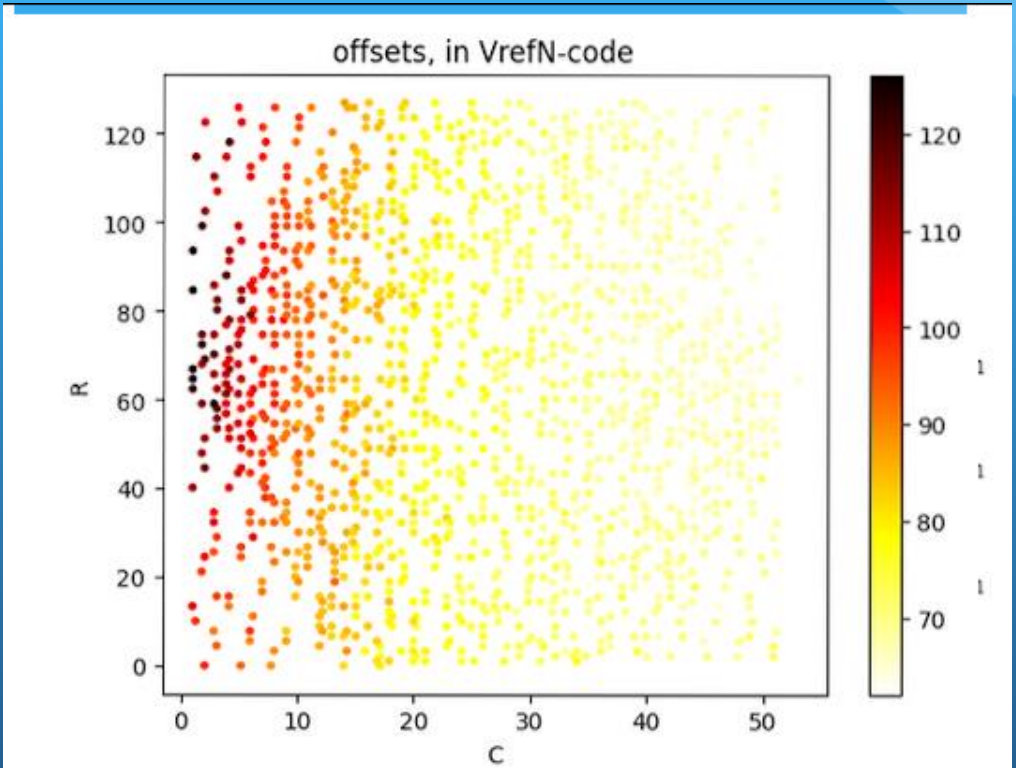
I. Laktineh

The time resolution was exploited to determine the position of the sources with a triangulation- based method

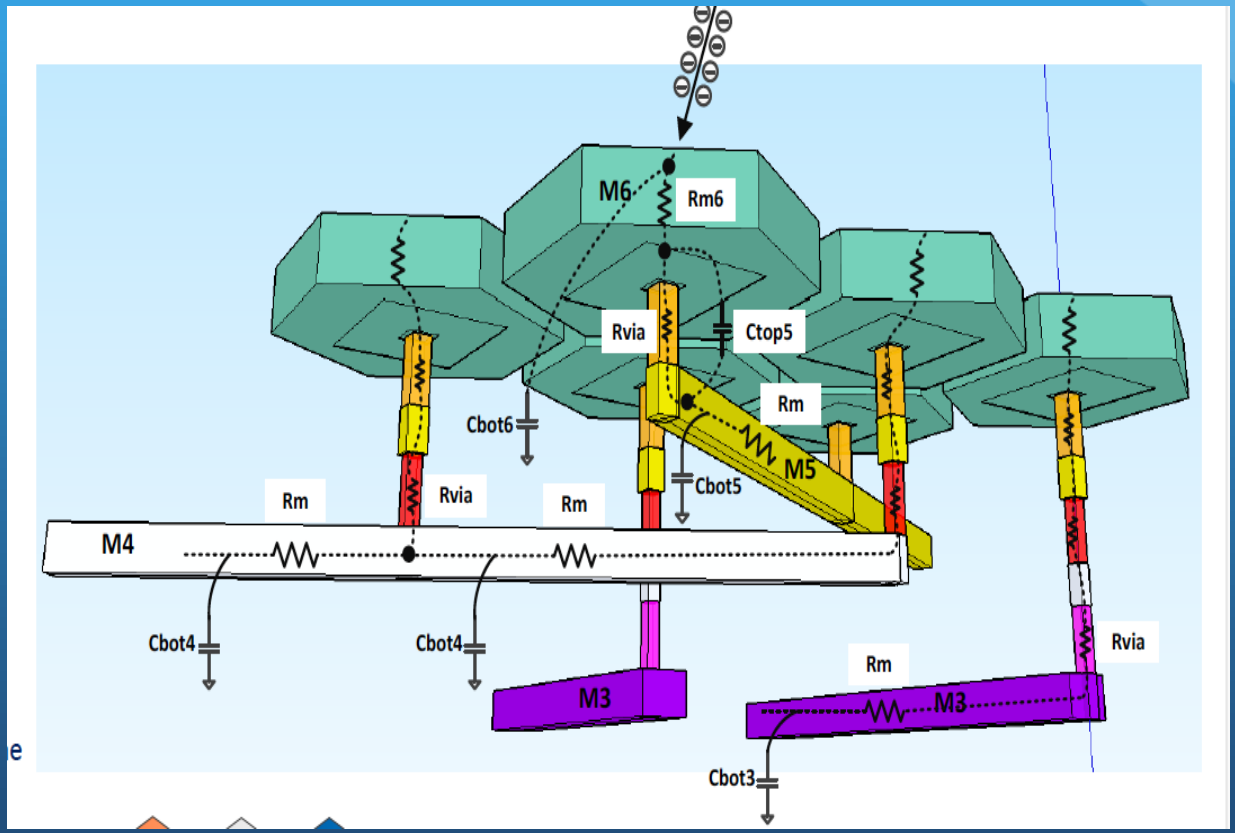




Noise level distribution



Cross-talk study is ongoing. This will determine the nature of the discriminator to be used (most probably current conveyer)



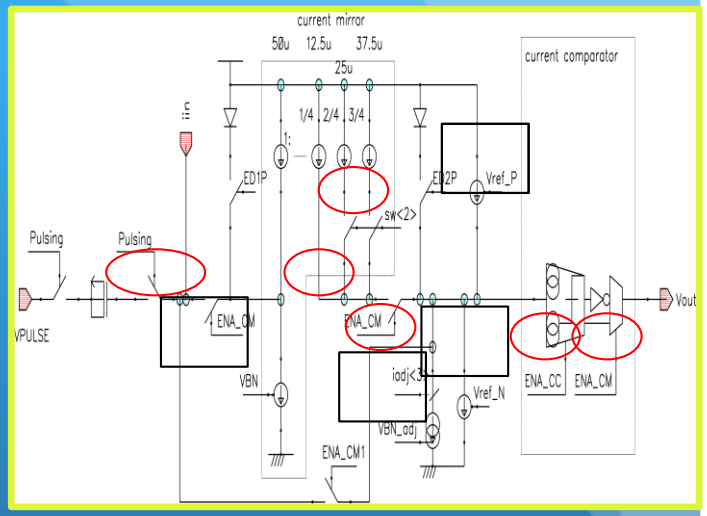
Pedestal threshold calibrations

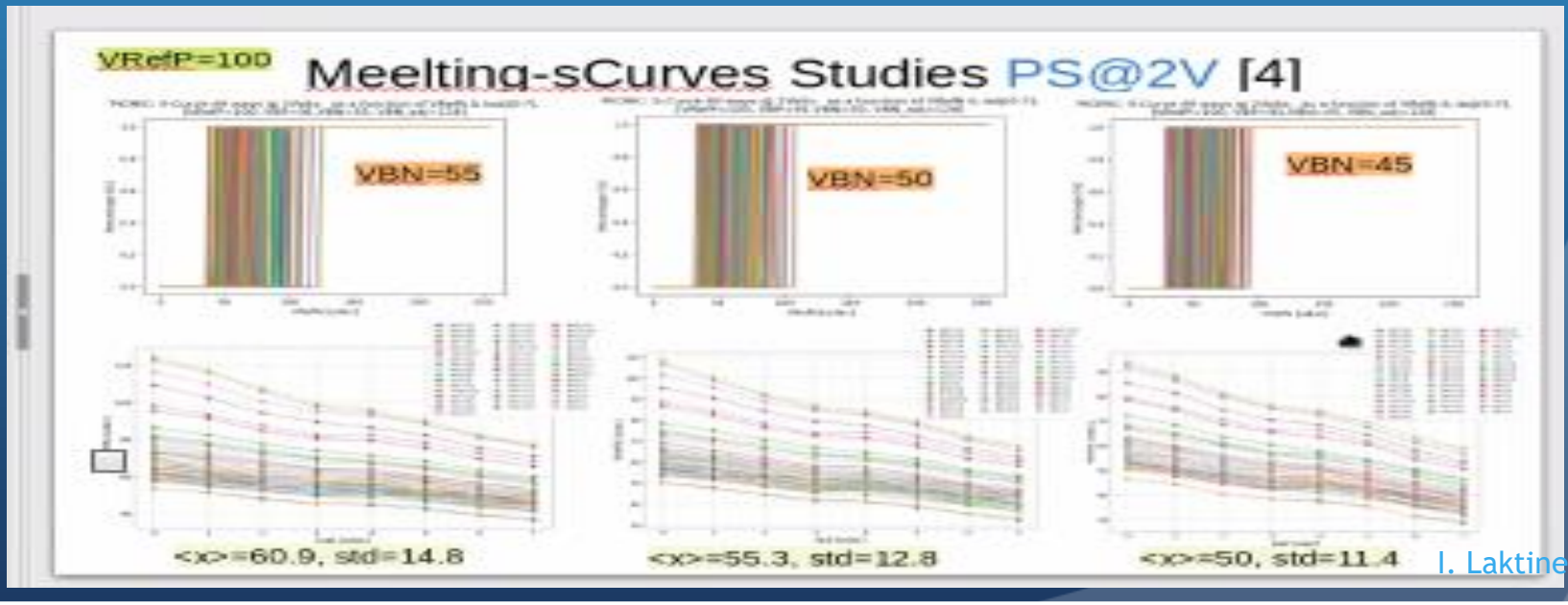
1) Freeze a set of **DAC**(Global) values driven by :
   - small dispersion between s-Curves
   - bigger number of sCurves in a given space of phase vs VRefN(quite sensitive)

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% in VRefN





I. Laktineh

PICMIC will be soon tested with a channeltron producing single electron of energy up to 30 keV in a MEB to have independent time and resolution measurement