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First results of the picosecond submicrometer detection concept (PICMIC)

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on behalf of PICMIC collaboration

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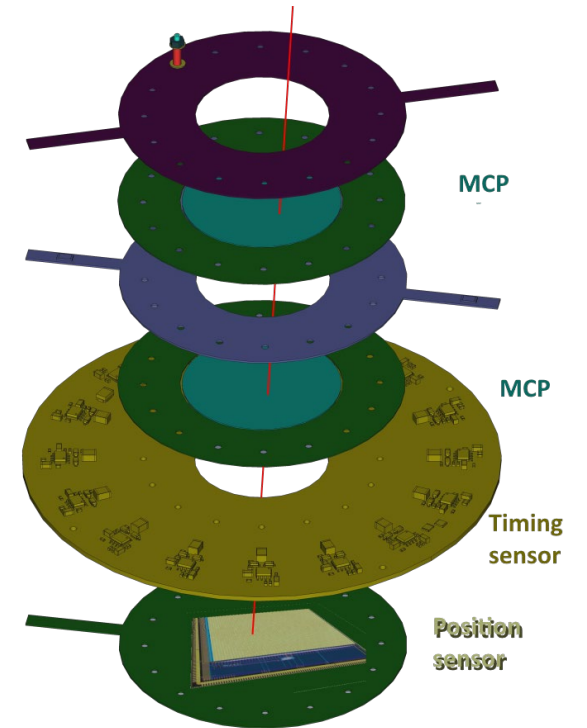
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INSTR 2026, Oct 12-16, 2026, Hefei, China

Outline

- ❑ Introduction
- ❑ PICMIC concept
 - ❖ Time measurement
 - ❖ Position measurement
- ❑ First demonstrator and results
- ❑ Improvements on timing and position measurement
- ❑ From MCP to NCP



Introduction – Micro Channel Plate (MCP)

Fast electron multiplication

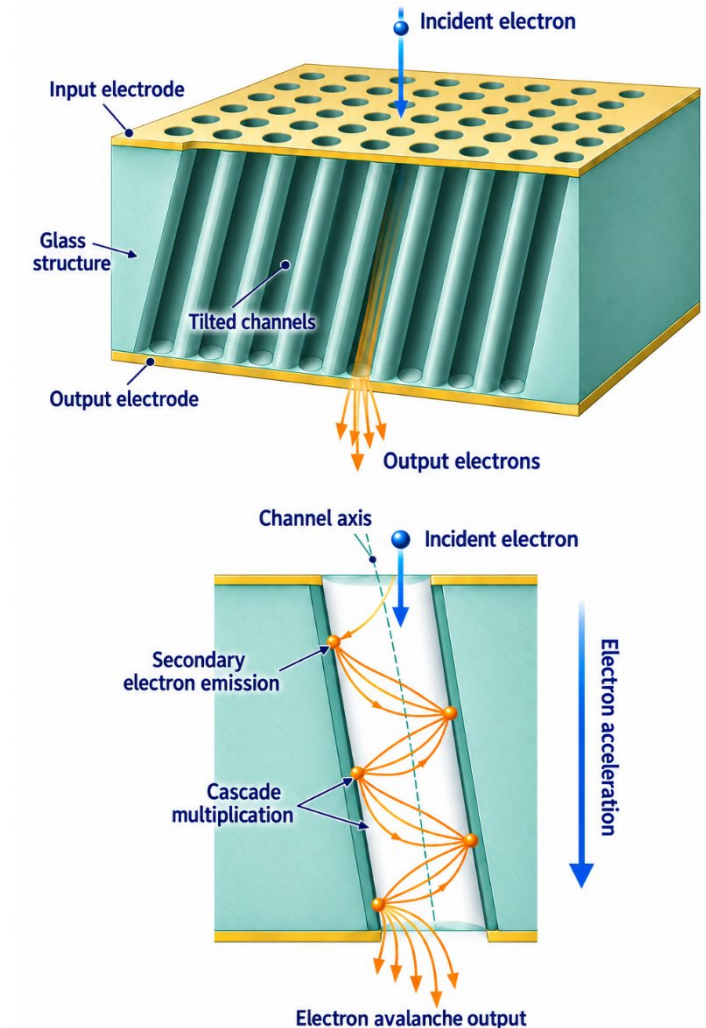
- ❑ Picosecond-scale timing motivates MCP-based detectors.
- ❑ MCP is one of the **best timing devices** with a few picoseconds resolution.

Micrometer-scale channels

- ❑ MCP has an excellent intrinsic spatial resolution since avalanches remain confined within pores **as small as 3 μm** .

Both timing and spatial information

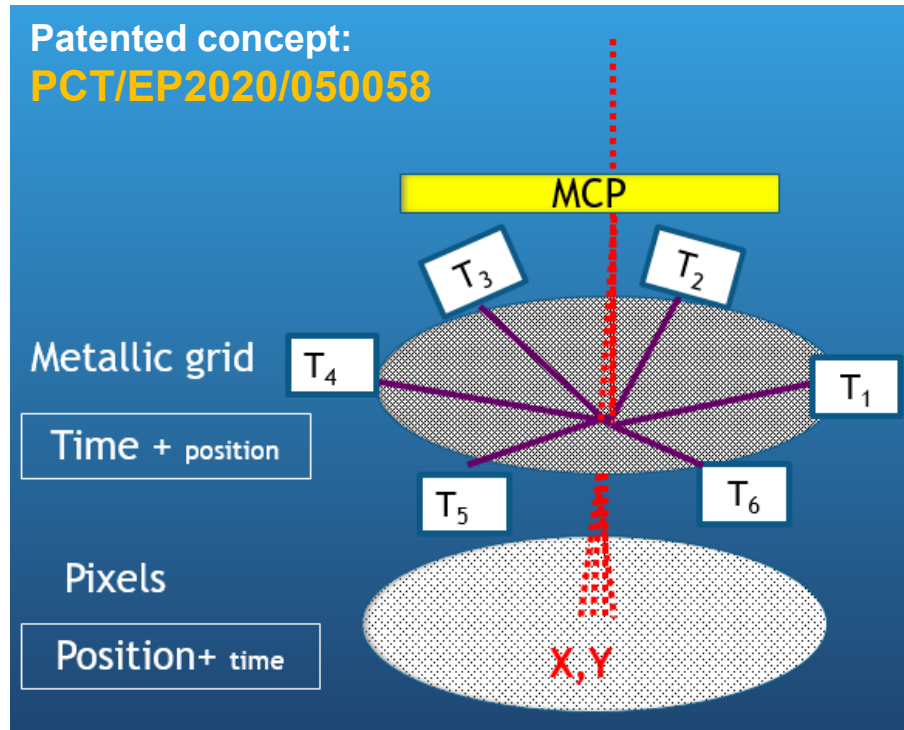
- ❑ MCP is often used for fast timing but spatial resolution is not appropriately explored.



PICMIC concept

❑ A new scheme to maximize MCP performance

- ❖ A **transparent grid** placed downstream the MCPs and read out at several points.
- ❖ A **pixel sensor** measuring the avalanche position with fewer readout channels.



Timing plane

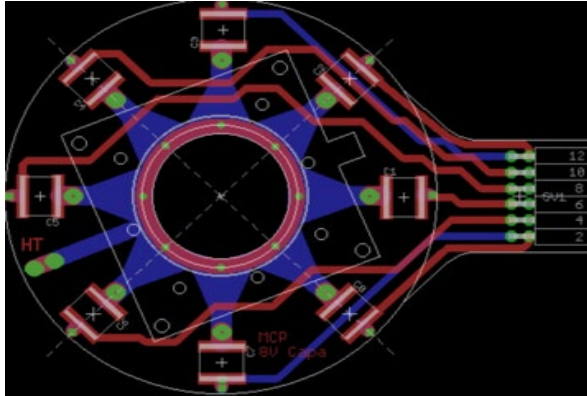
- ❖ Delay plane concept
- ❖ The MCP anode can act as the grid

Position plane

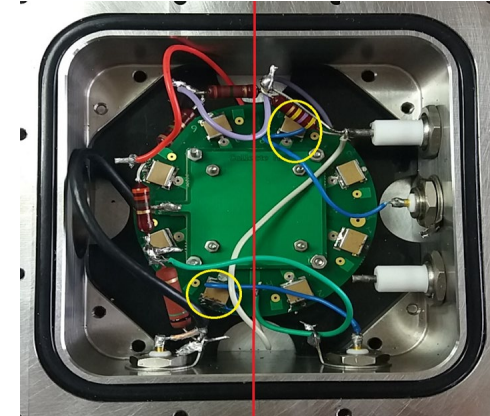
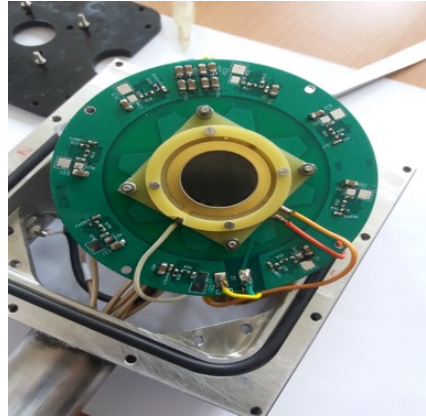
- ❖ Micro pixels locate the avalanche
- ❖ Woven strips
- ❖ 3D interconnected pixels concept

Use (x,y) to subtract the time propagation on the grid and then improve on time measurement : $T_{\text{abs}} = \frac{\sum_0^N T_i - T_{i-\text{propag}}}{N}$

Time measurement



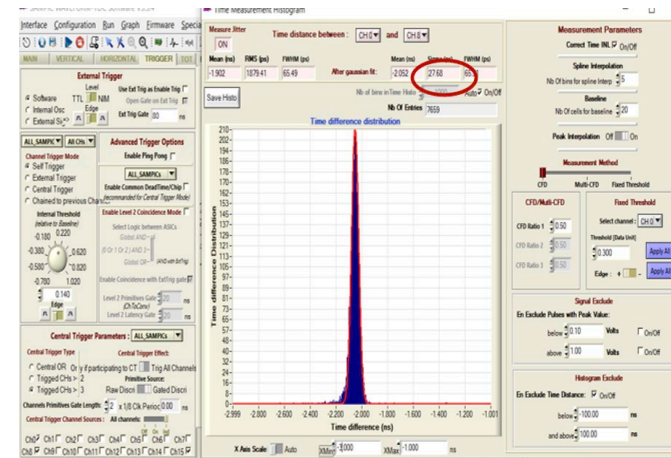
Delay-plane readout



Setup with two MCPs of 2.5 cm diameter to validate the delay-plane principle



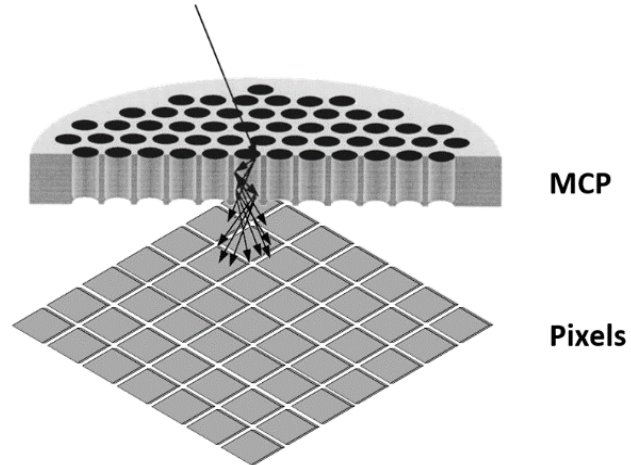
SAMPIC: a waveform digitizer (3ps)



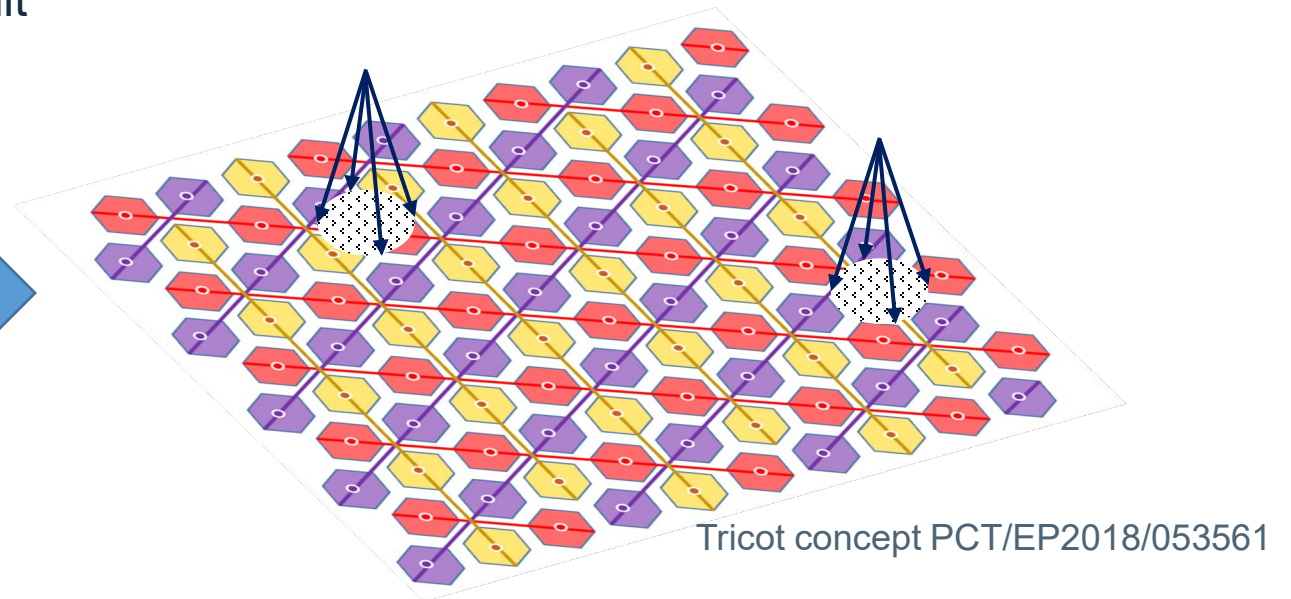
$$\sigma_{T_i - T_j} = 30 \text{ ps} \rightarrow \sigma_T = 8 \text{ ps}$$

Position measurement

- ❑ Woven strips reduce the channel count
 - ❖ Pixels connected in woven strips based on the tricot concept
 - ❖ Neighboring collection pixels connect to different strips.
 - ❖ Each strip has one readout channel
 - ❖ Charge sharing activates a few strips
 - ❖ The fired strip intersection identifies the hit



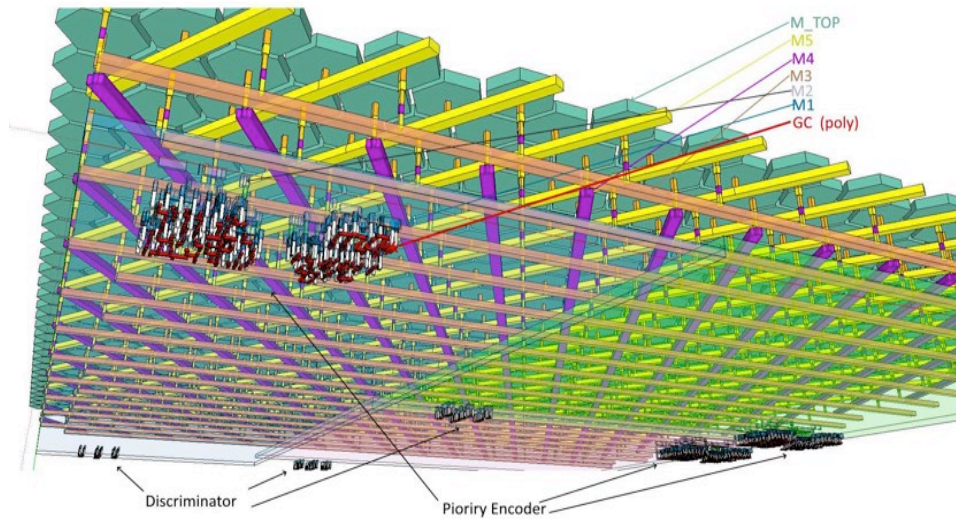
$N \times N$ pixels



3N readout channels

Reduction of readout channels, power consumption and occupancy 6

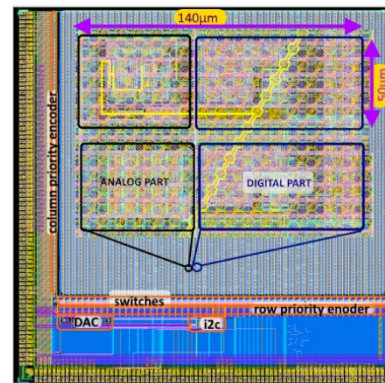
Pixel sensor prototype (PICMIC0)



2,216,000

pixels at 5 μm pitch

2,556 readout cells

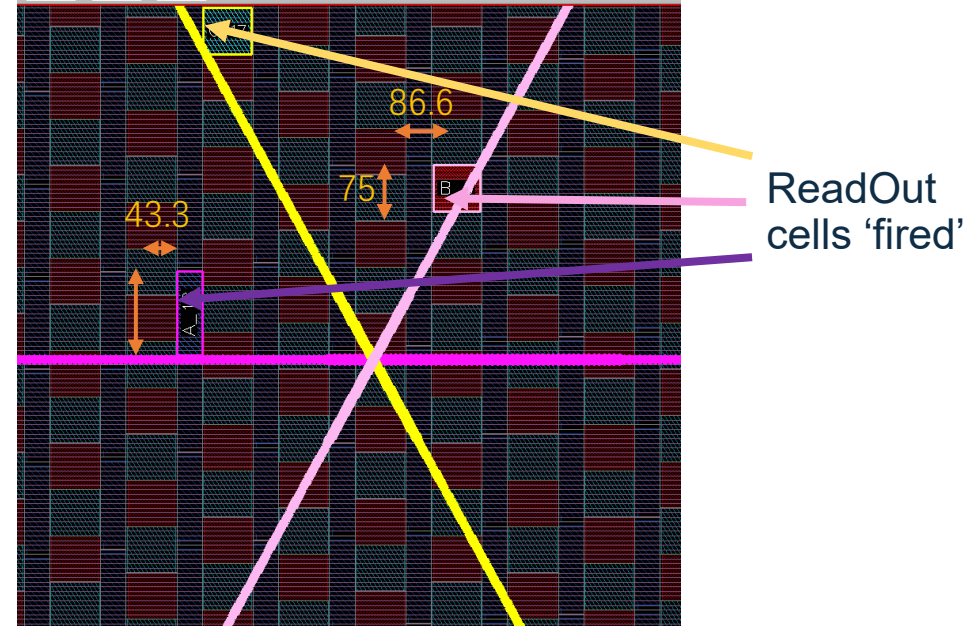
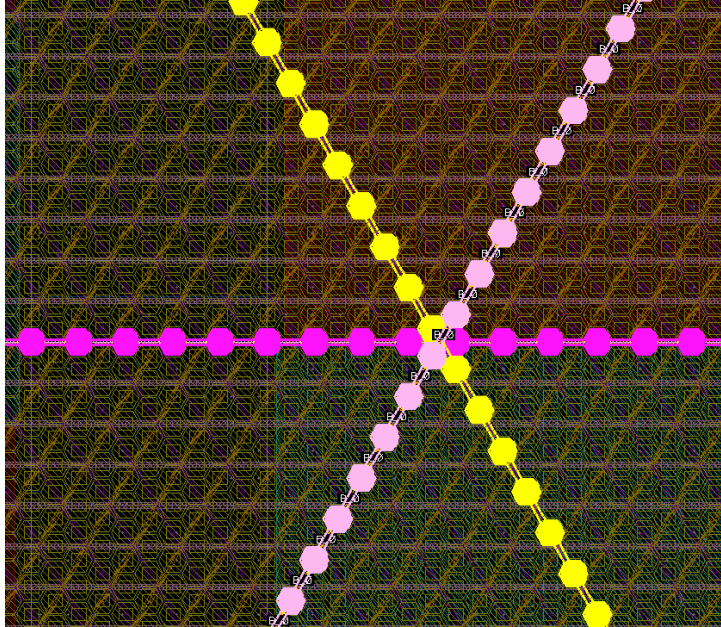


Six metal layers, current-conveyor front end and priority encoder

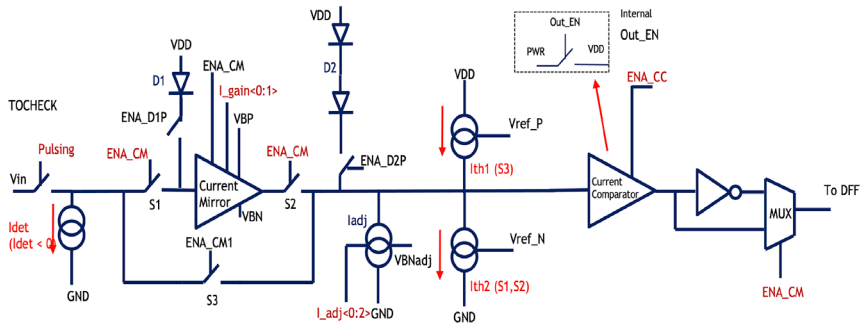
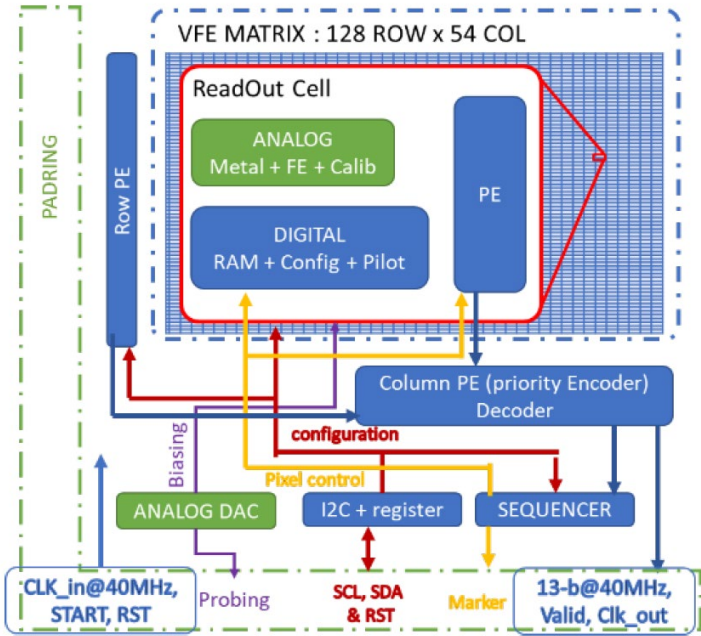
Parameter	PICMIC0
Design flow	Cadence DoT
Technology	TJ CIS 180 nm
Supply	1.8 V
Analog static power	>172 mW/cm ²
Die size	~7.5 × 7.5 mm ² (6.5 × 7.5 mm ²)
Anode area / pitch	~22 μm^2 / 5 μm
Readout cell	50 × 140 μm^2
Readout matrix	128 × 54; 2,556 active
Input clock	40 MHz
Output / I/O	13-bit parallel / CMOS
Slow control	I ² C
Maximum data rate	390 Mbps at 1 MHz hits

Hit reconstruction from strip intersections

Pixels deliver signals to their associated readout cells.

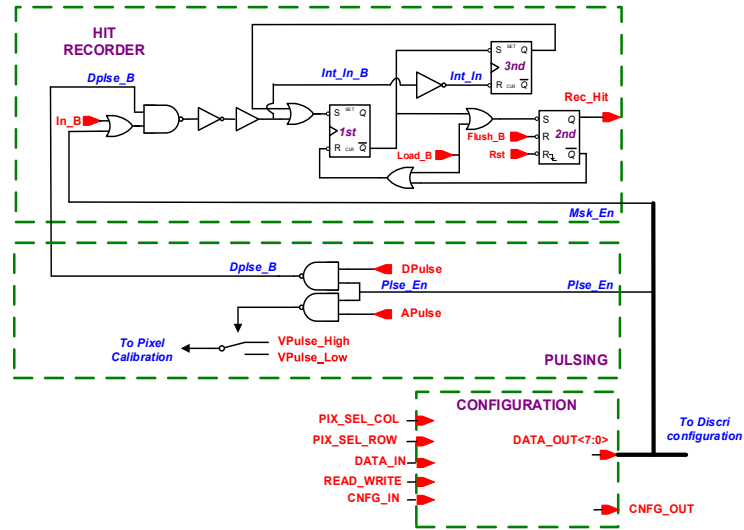


Intersect the fired strips to reconstruct the hit position

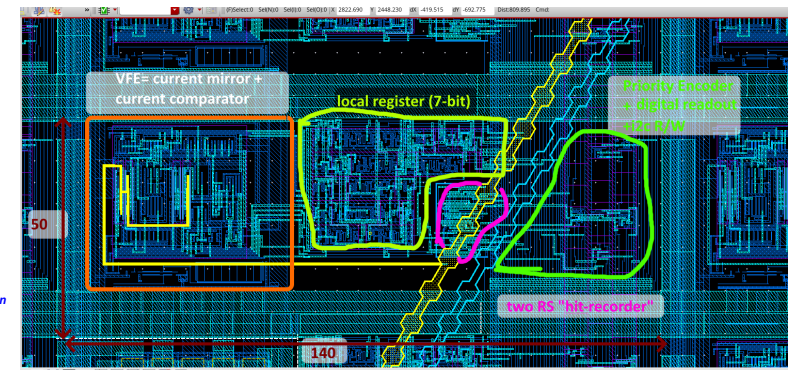


In-pixel analog circuit

- ❑ Current conveyor preamp followed by a comparator.
- ❑ Five 8-bit DACs are used to control the preamp and the comparator response globally.
- ❑ One 3-bit DAC to correct the threshold of each pixel.
- ❑ Priority encoder is used to read out only the hit.



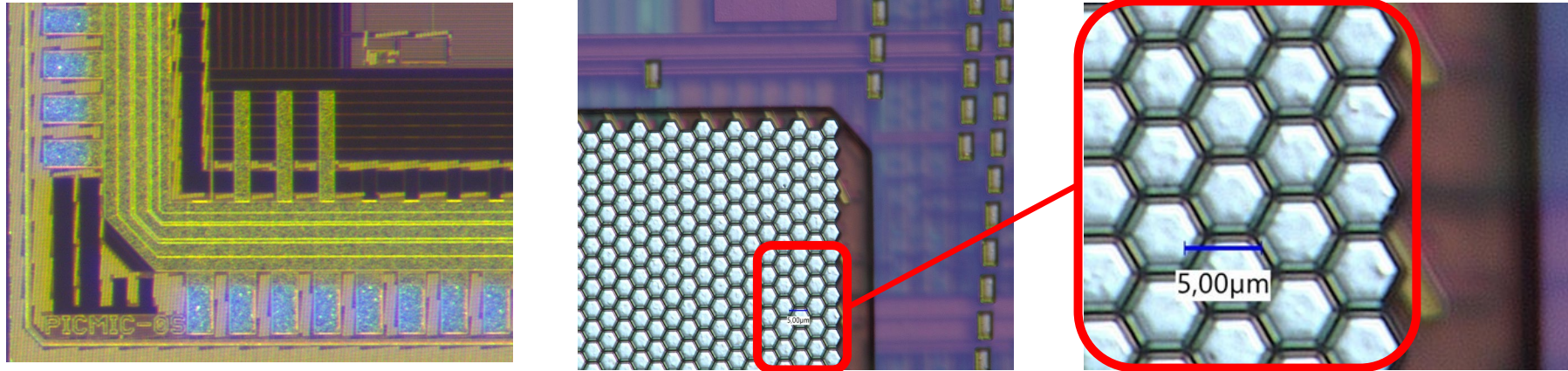
In-pixel digital circuit



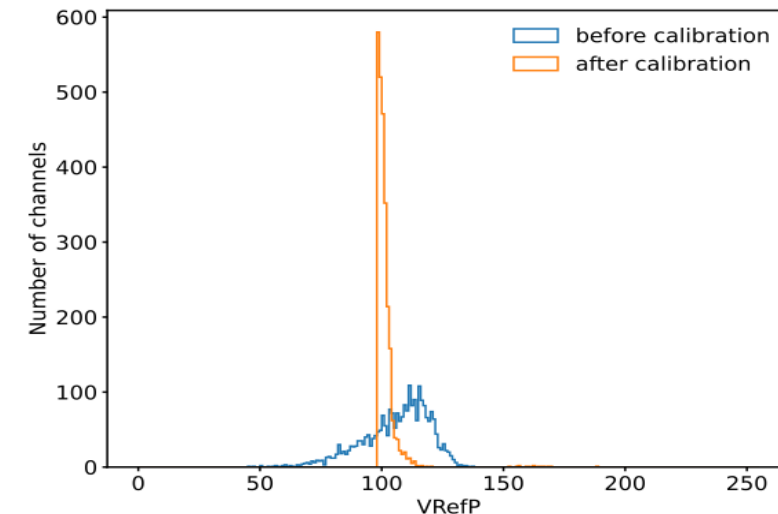
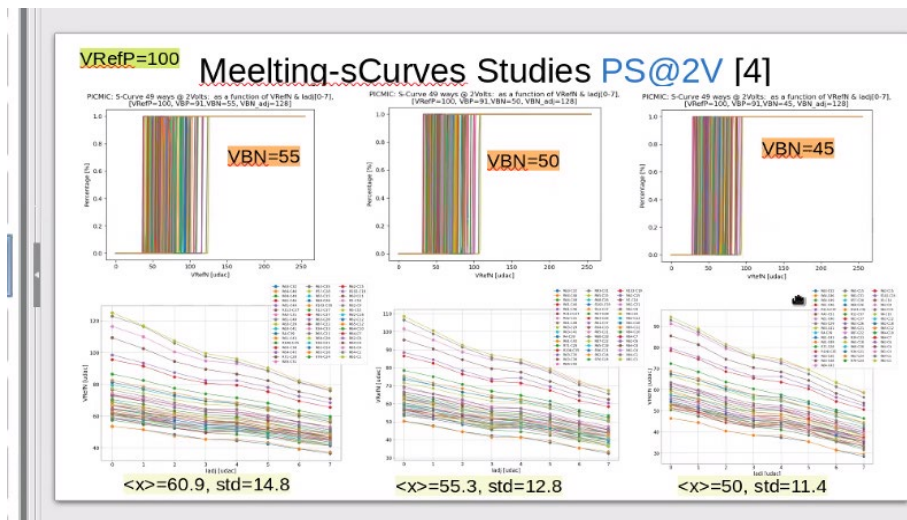
Pixel layout

PICMIC0 fabrication and calibration

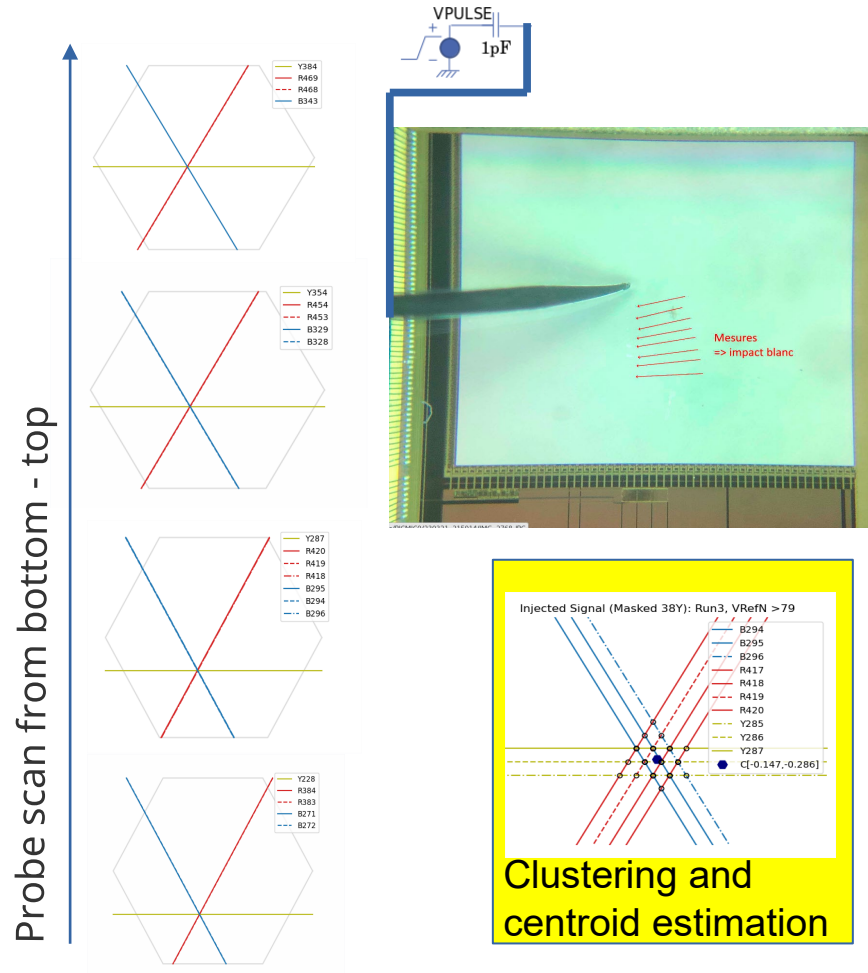
Submitted in November 2021 and received in July 2022



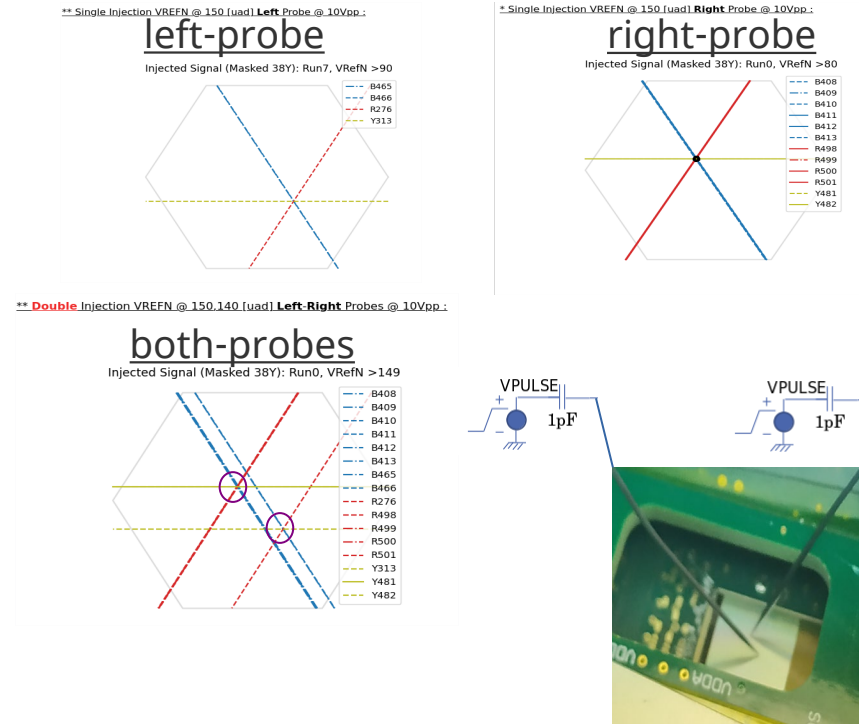
3-bit local DAC calibrates the S-curve dispersion of the 2,556 channels.



Direct charge-injection tests



Two probes injection

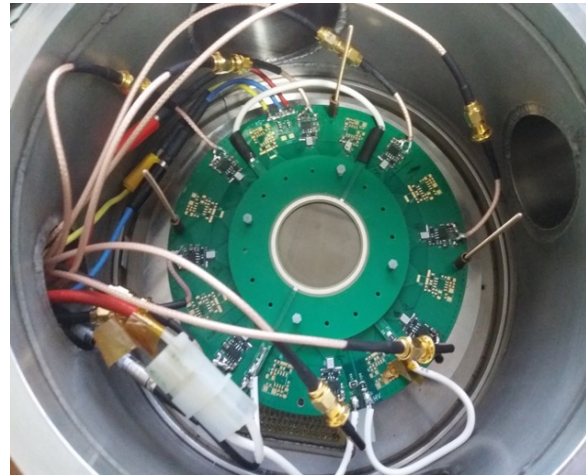
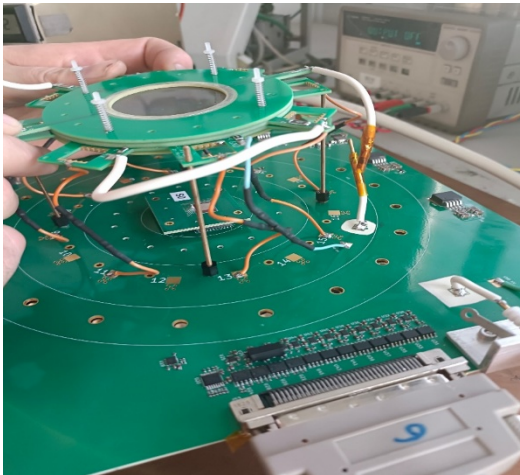
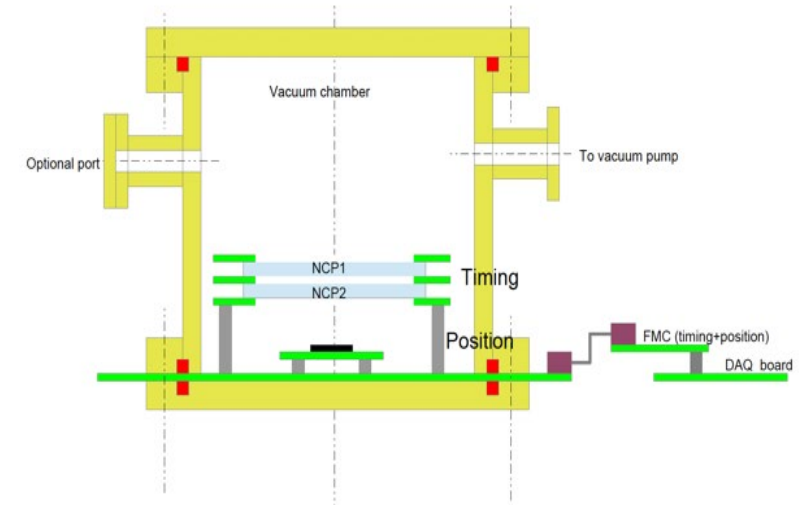


Single- and two-probe tests clustering and hit reconstruction

The first PICMIC demonstrator

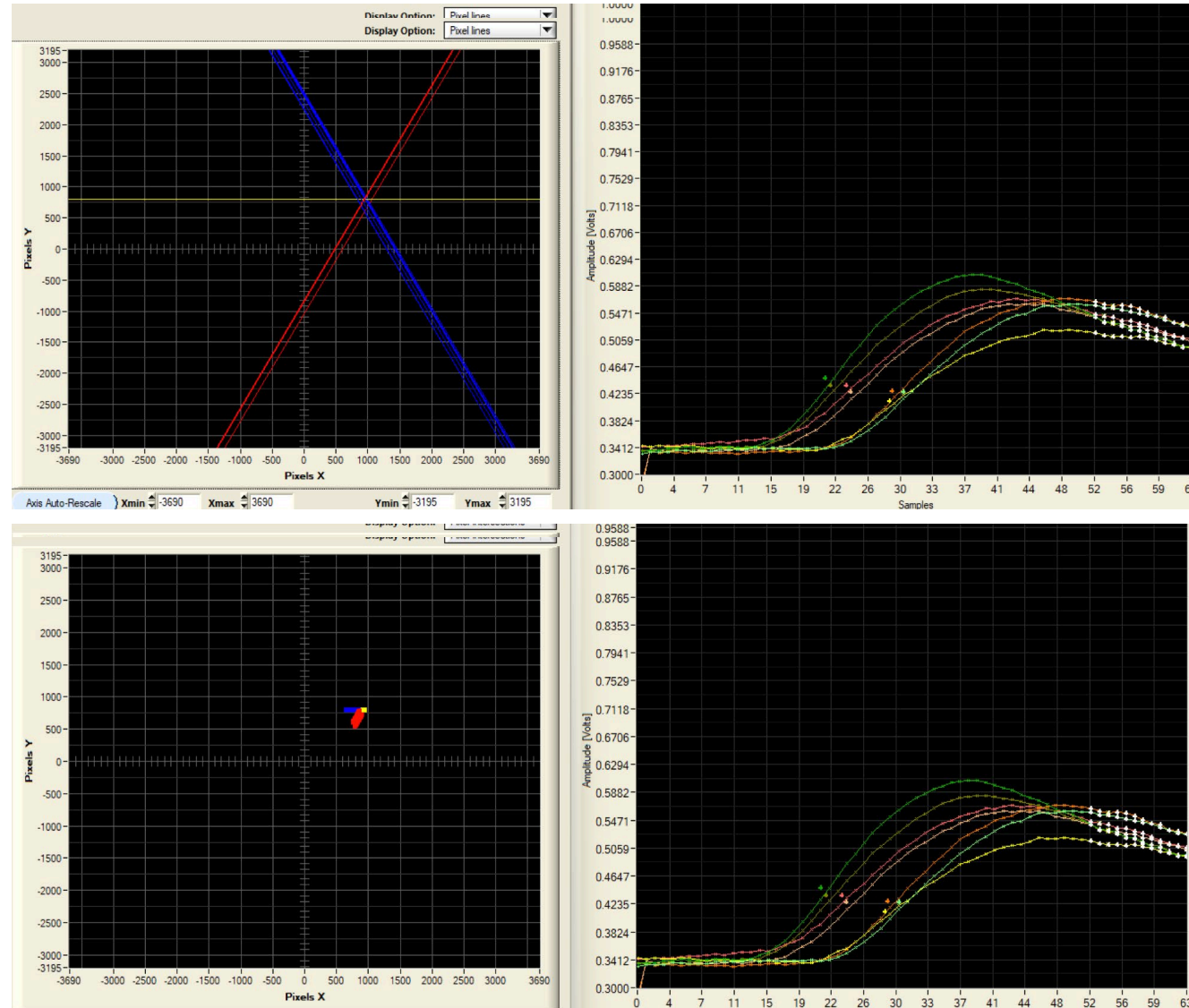
Two 5 cm MCPs in a vacuum assembly

- ❑ 16 timing positions, 8 instrumented
- ❑ Pixel sensor mezzanine and master board
- ❑ Shared 40 MHz clock for timing and position



Synchronous position and timing signals

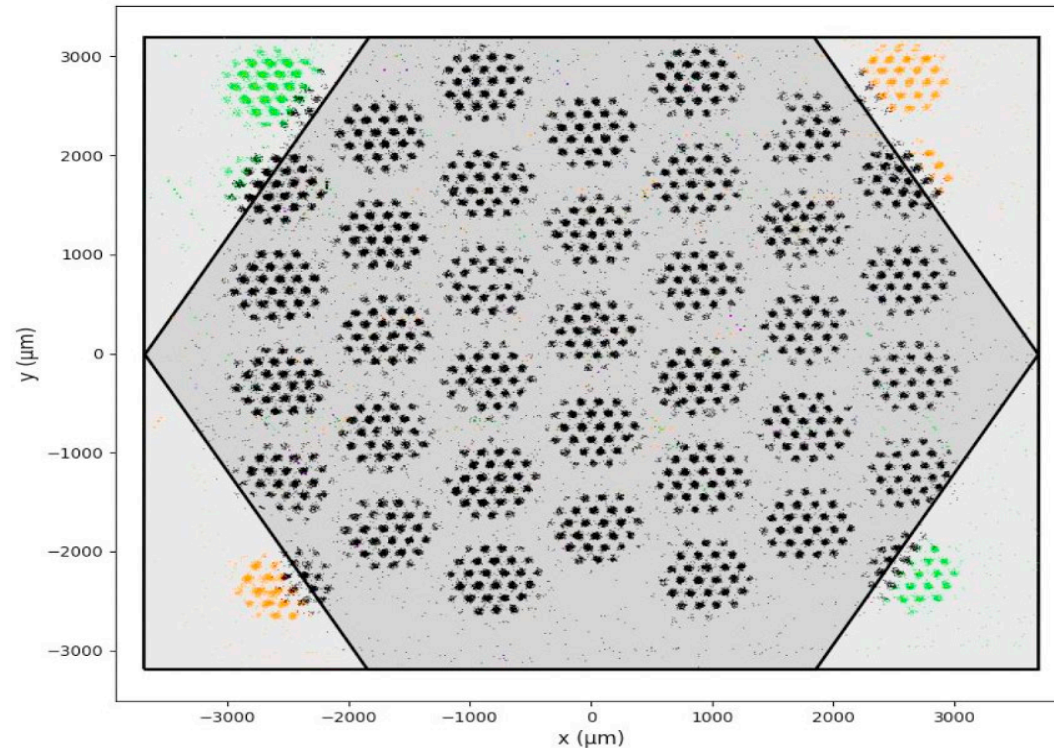
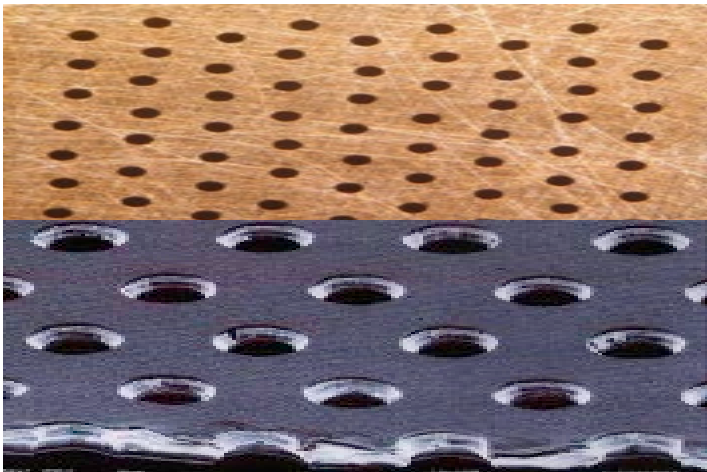
Test with collimated α and γ sources



Spatial resolution with a perforated mask

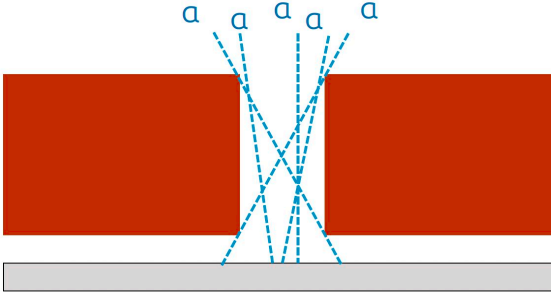
α source placed on a perforated mask and a GEM foil

Mask: 0.3 mm holes, 0.8 mm pitch
GEM foil: 50 μm holes, 140 μm pitch



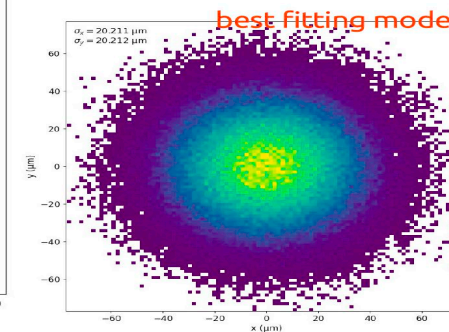
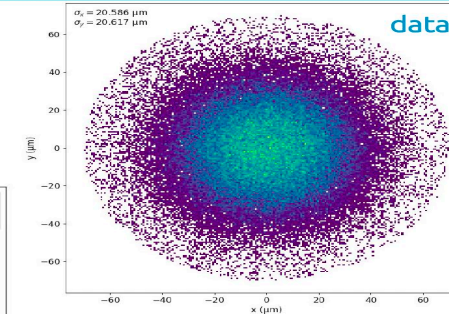
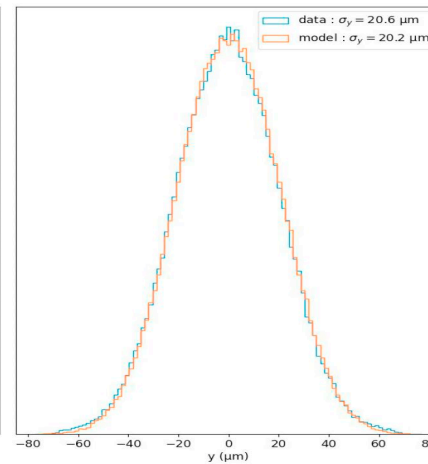
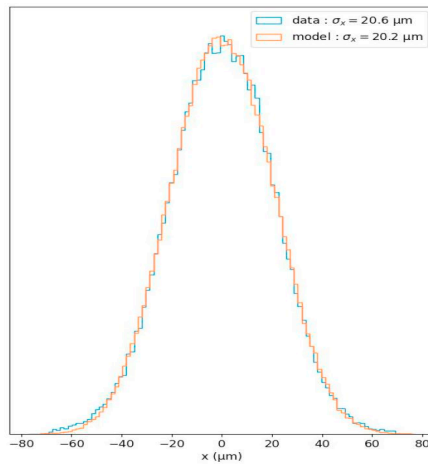
The reconstructed image resolves the fine hole pattern.

Spatial resolution from data–simulation fits



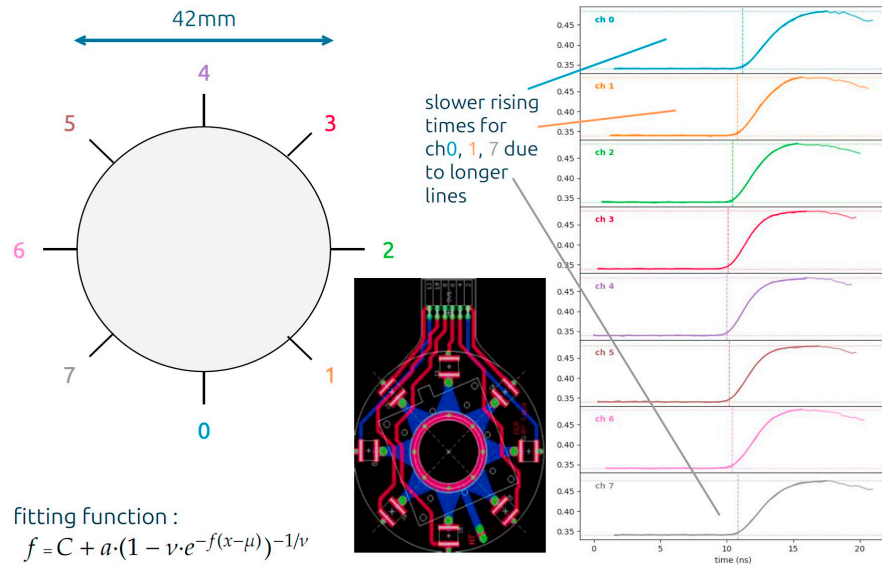
- ❑ Simulate α trajectories and MCP impact points.
- ❑ Convolve the impact with a 2D gaussian distribution.
- ❑ The best data-simulation fit provides the spatial resolution.

Best fit $\rightarrow \sigma_x = \sigma_y = 14.5 \mu\text{m}$

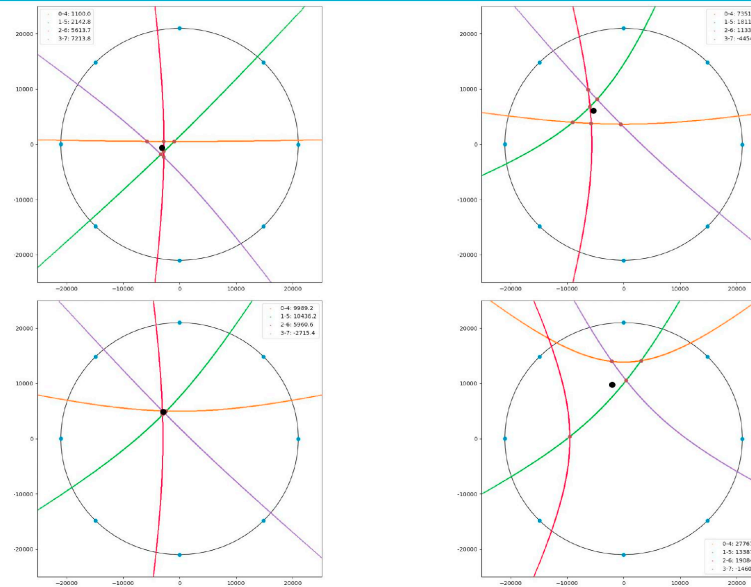


Position information from the timing plane

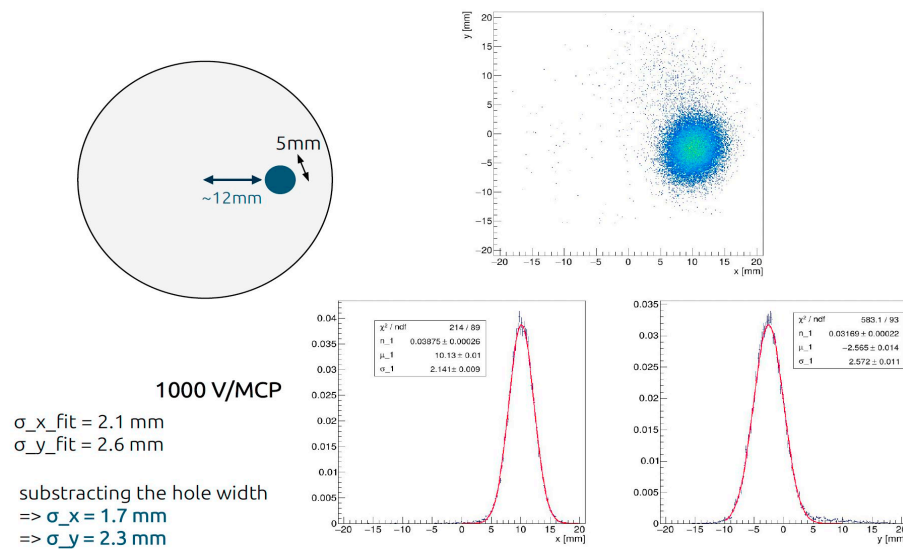
Timing detector



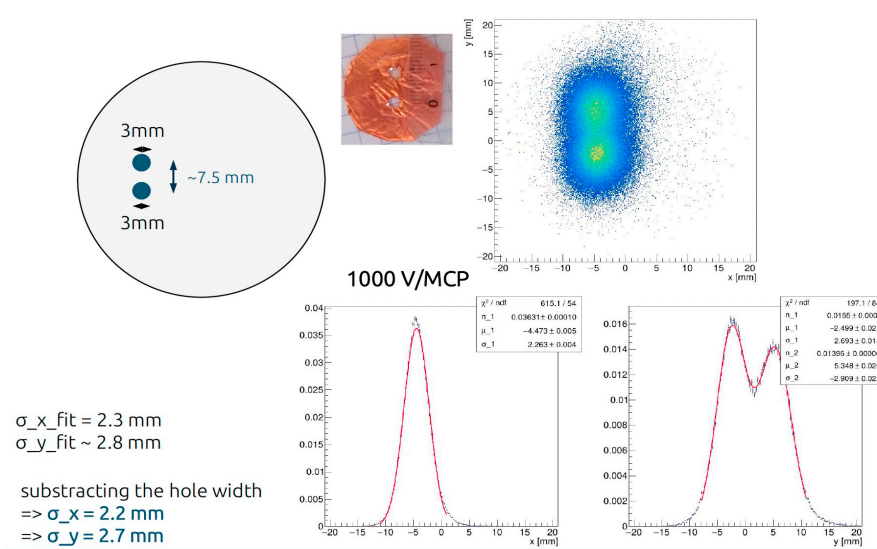
Timing detector – position reconstruction



Timing detector – position resolution



Timing detector – position resolution



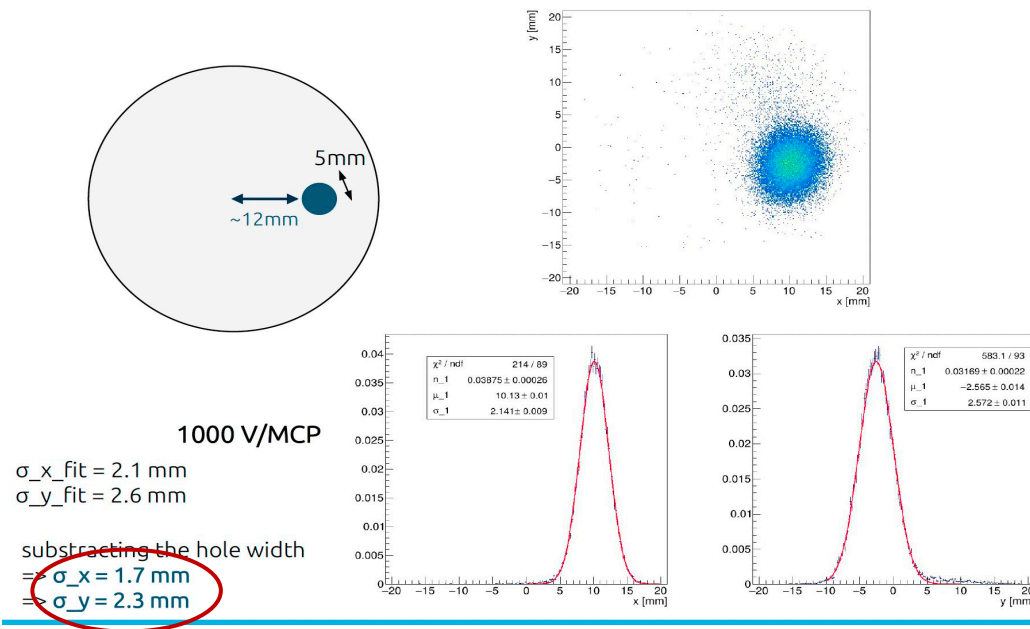
Timing differences locate hits at the mm scale.

Demonstrator timing performance

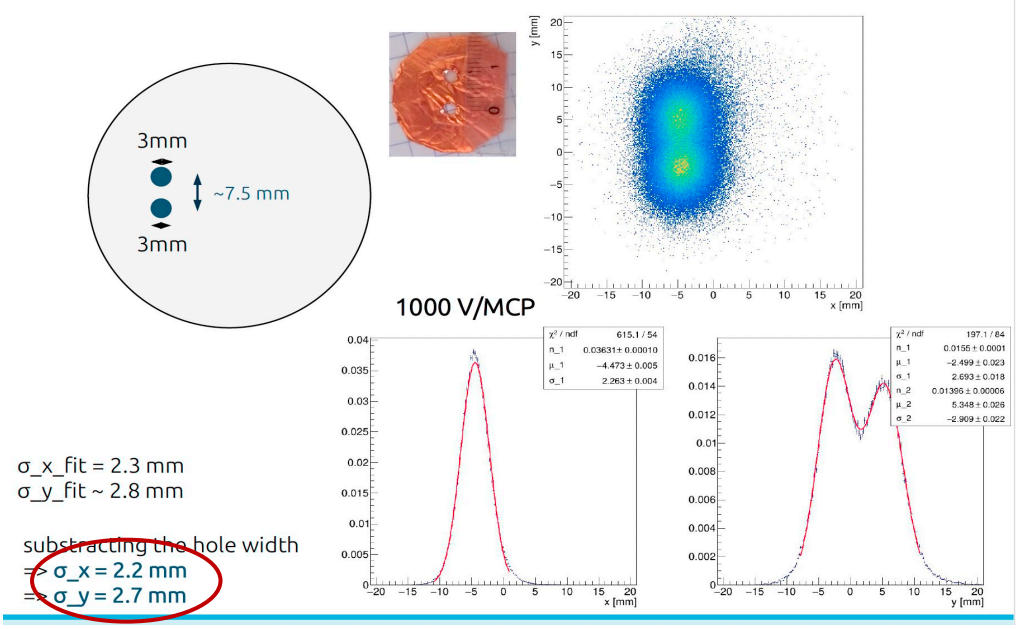
15 ps

timing resolution

Timing detector – position resolution



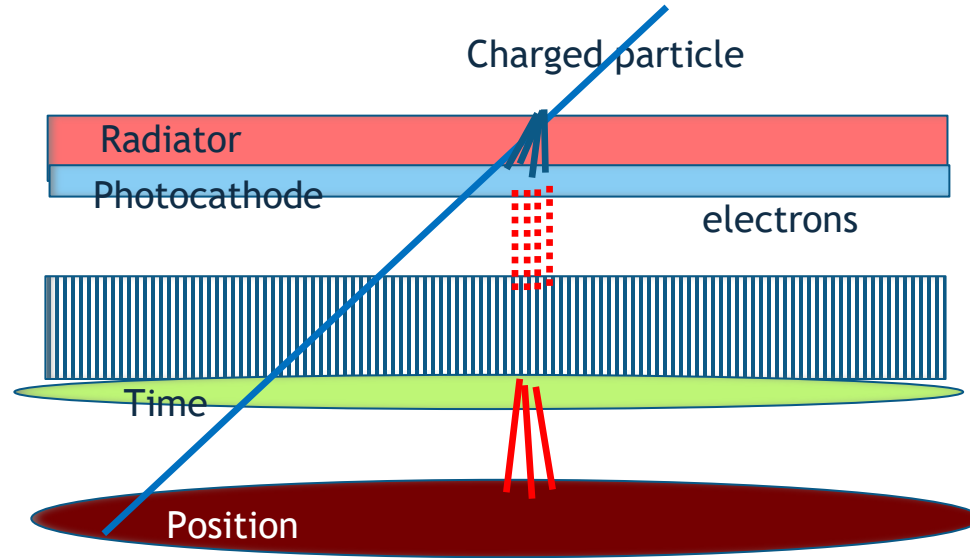
Timing detector – position resolution



The next PICMIC system

- ❑ A larger, more uniform pixel sensor
- ❑ Faster timing electronics
- ❑ Higher acquisition rates
- ❑ Synchronized data acquisition

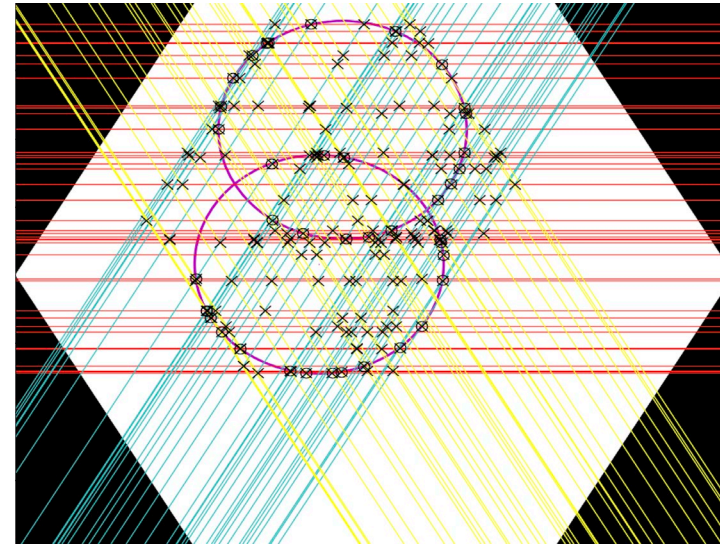
PICMIC for charged-particle tracking



Radiator should fulfil two constraints:

- 1) Enough Cherenkov photons
- 2) Small material budget

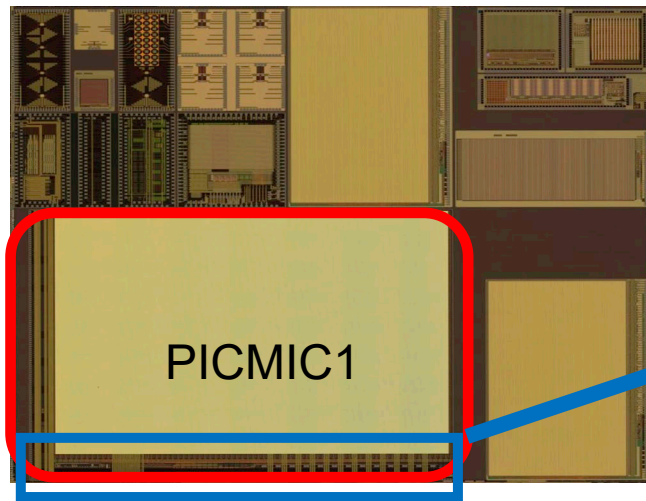
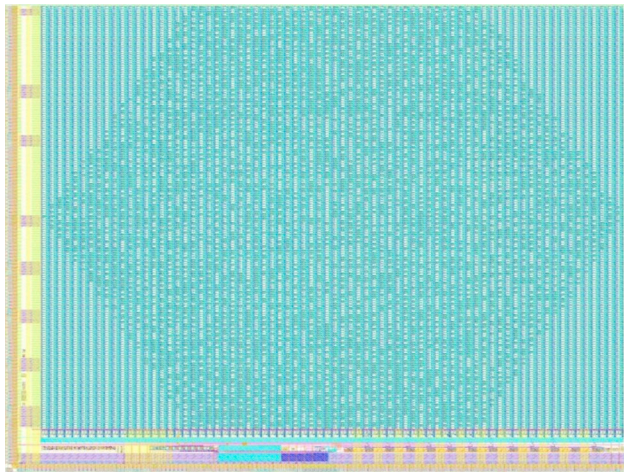
Planned test: 3 mm MgF_2 radiator with a DLC coating applied at CERN



Cherenkov rings construction
using Hough Transform

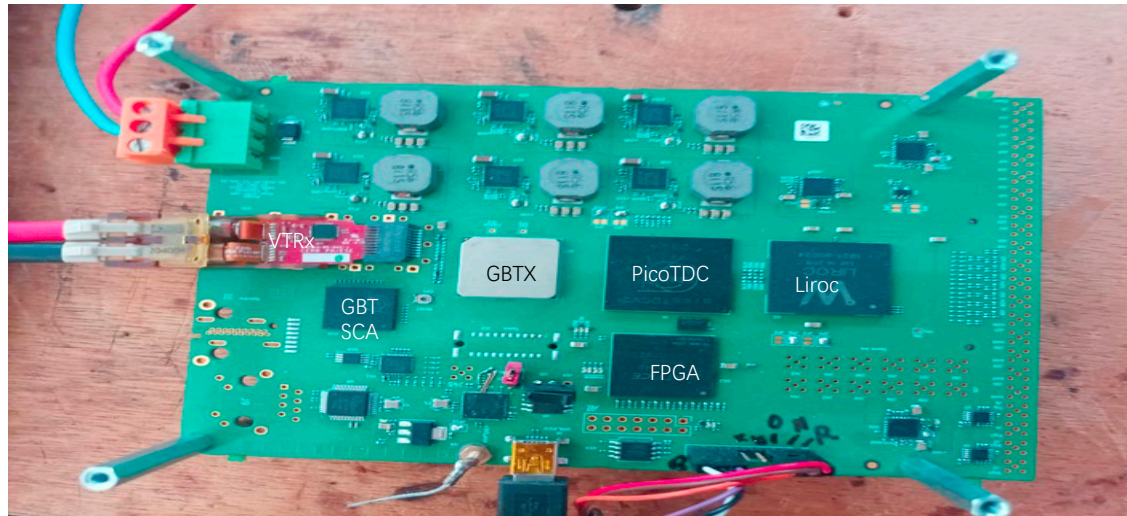
PICMIC1 spatial-readout upgrades

- ❑ **8-bit DAC calibration** to improve channel uniformity
- ❑ **10–30 MHz target rate** with independent column readout
- ❑ **$1.2 \times 1.4 \text{ cm}^2$ sensor** to increase the surface by a factor of 4
- ❑ **Charge preamplifier** to avoid current smearing on long tracks
- ❑ Selected channel outputs also support external TDC tests



Faster timing electronics

- ❑ SAMPIC dead time is approximately $1.25\text{ }\mu\text{s}$
- ❑ Timing measurement with a TDC is needed
- ❑ A board integrating **LIROC** (OMEGA lab) and **picoTDC** (CERN) is developed
- ❑ GBTX (CERN) is used to communicate with the DAQ system



10 ps is measured with 1 pC charge injection

Data acquisition

IDROGEN / IN2P3



Development in progress

- ❑ Interface/mezzanine boards connect timing and position boards
- ❑ Firmware synchronizes the two data streams

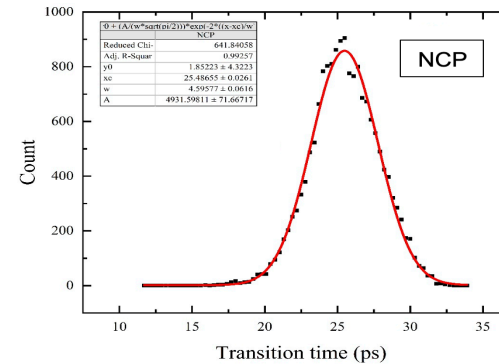
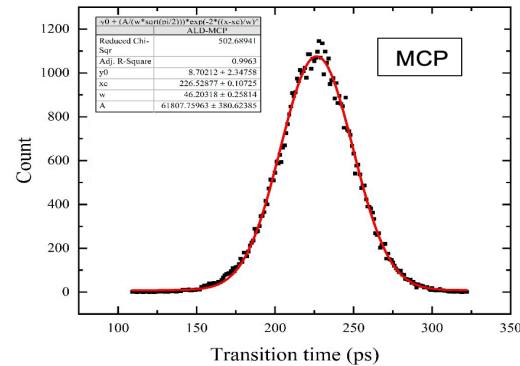
First tests planned before the end of 2026

Nanochannel plates (NCP)

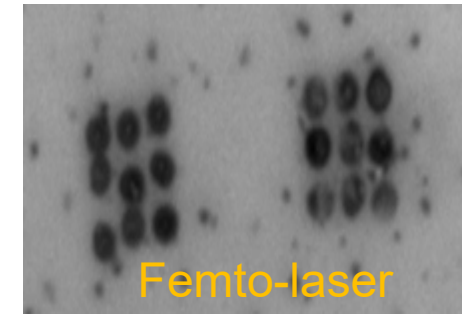
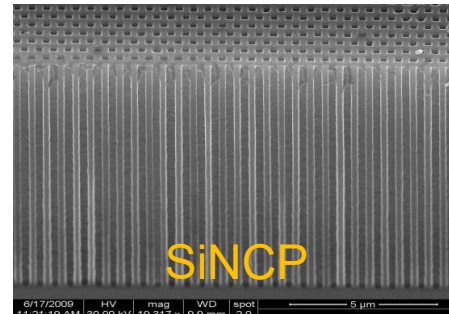
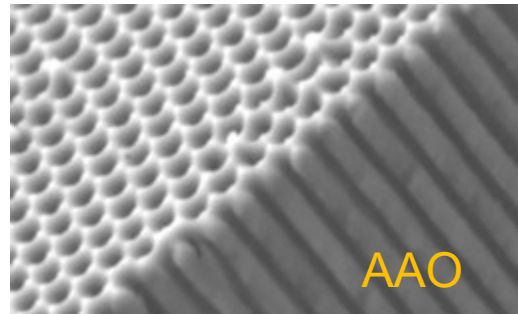
Smaller pores to pursue finer position and time resolution

Nanochannel plates

- ❑ Nanochannel plate (NCP) is being developed
- ❑ Nanoholes will be coated with emissive and resistive materials
- ❑ At least ten times better timing and spatial resolution

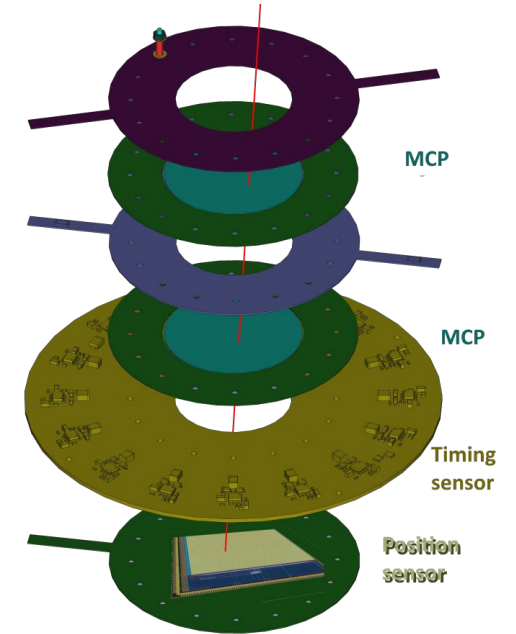


- ❑ Three fabrication approaches are being investigated
 - ❖ Anodized Aluminum Oxide (AAO)
 - ❖ Silicon electrochemical etching
 - ❖ Femto-laser digging



Summary

- ❑ The PICMIC demonstrator validates combined time and position readout of MCP
- ❑ Timing resolution of 15 ps has been achieved
- ❑ Spatial resolution of 15 μm has been achieved
- ❑ Next PICMIC generation will allow to explore the potential of MCP
- ❑ PICMIC can be used as a timing tracker as well as a precise 4D camera
- ❑ NCP aiming to reach 1 ps and submicrometre resolution is being developed



Thank you