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# A Single Photon Counting X-ray Detector with 25 µm Pixel Pitch

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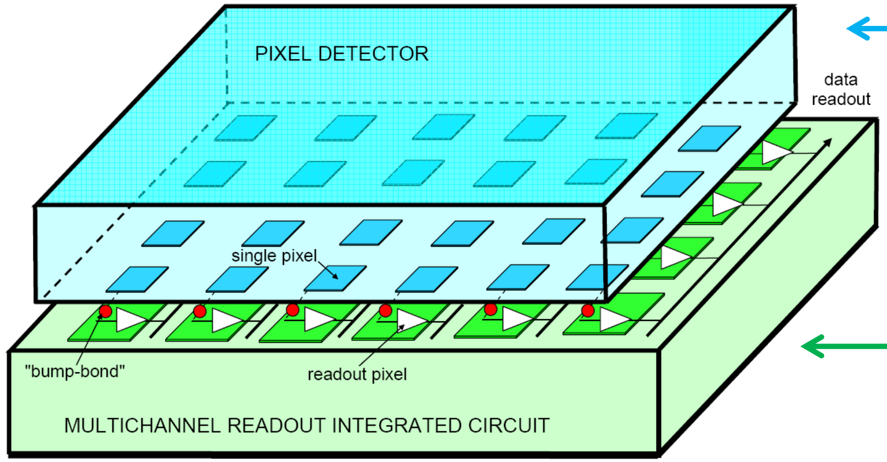
# Introduction – Hybrid Pixel Detector (HPD)

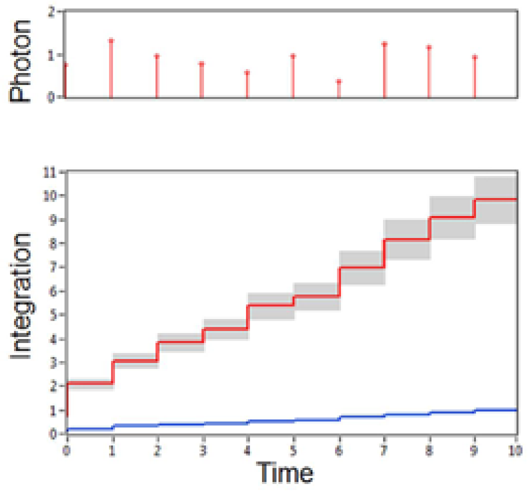
HPD
for X-ray imaging
application



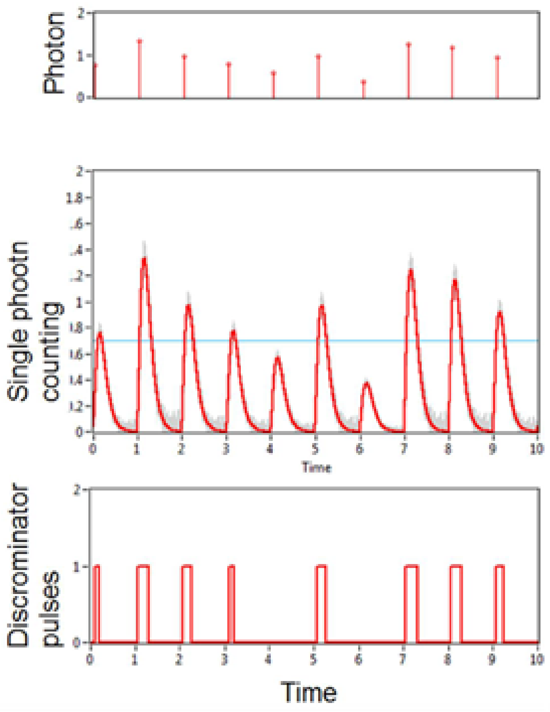

Detector material suitable for given application and X-ray energy range (Si, GaAs, CdTe, etc)

VLSI technology siutable for analog and digital block for readout electronics

Integration IC:




Single photon counting (SPC) IC:



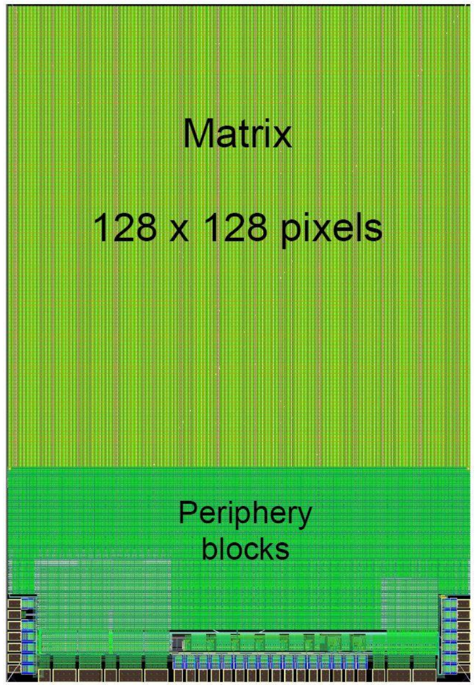

Trends for SPC chips:

- Small pixel area
- High count rate
- Energy measurements
- Large area detector (TSV)
- Continuous fast readout

**Talk outline:**

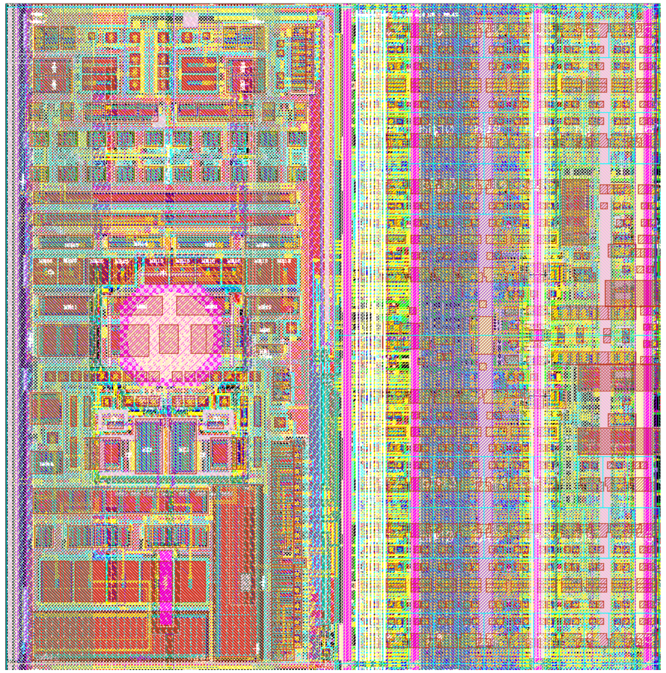
- **Readout IC architecure**
- **Measurements with Si sensor**
- **Summary and next steps**

SPC IC with
25 μm Pixel Pitch

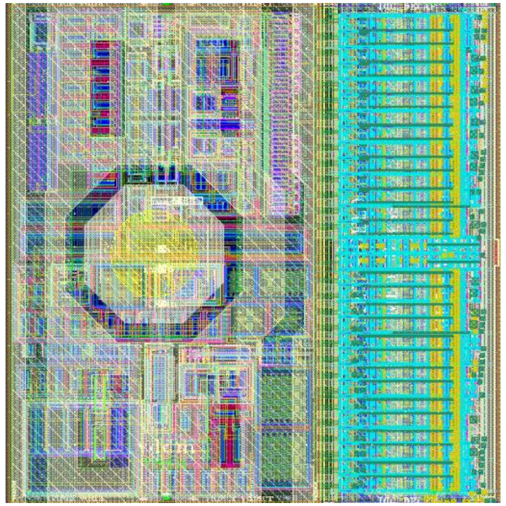


# Comparision of pixel size in different SPC ROIC

**PXD18k:**
pixel 100 x 100 µm$^2$



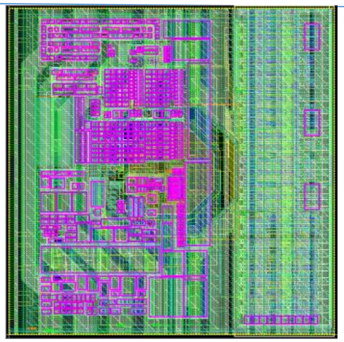

**UFXC, LNPX:**
pixel 75 x 75 µm$^2$



**XSPA-500k**

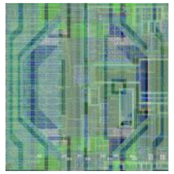

**XSPA-400 ER**


**SPHIRD:**
size 50 x 50 µm$^2$



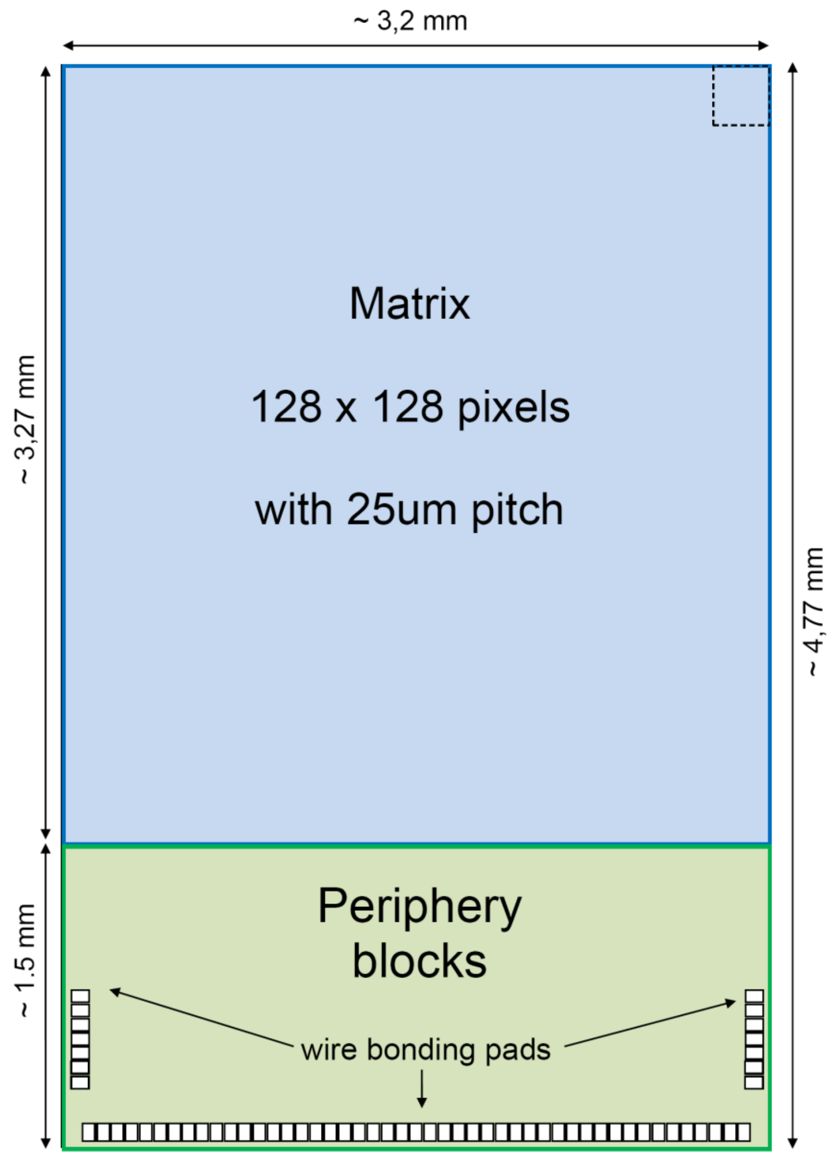
**European Synchrotron Radiation Facility (ESRF)**


**PIX25:**
25 x 25 µm$^2$



**Motivation:**
1. High spatial resolution
2. High count-rate per mm$^2$

# Single photon counting ROIC in 40 nm CMOS technology



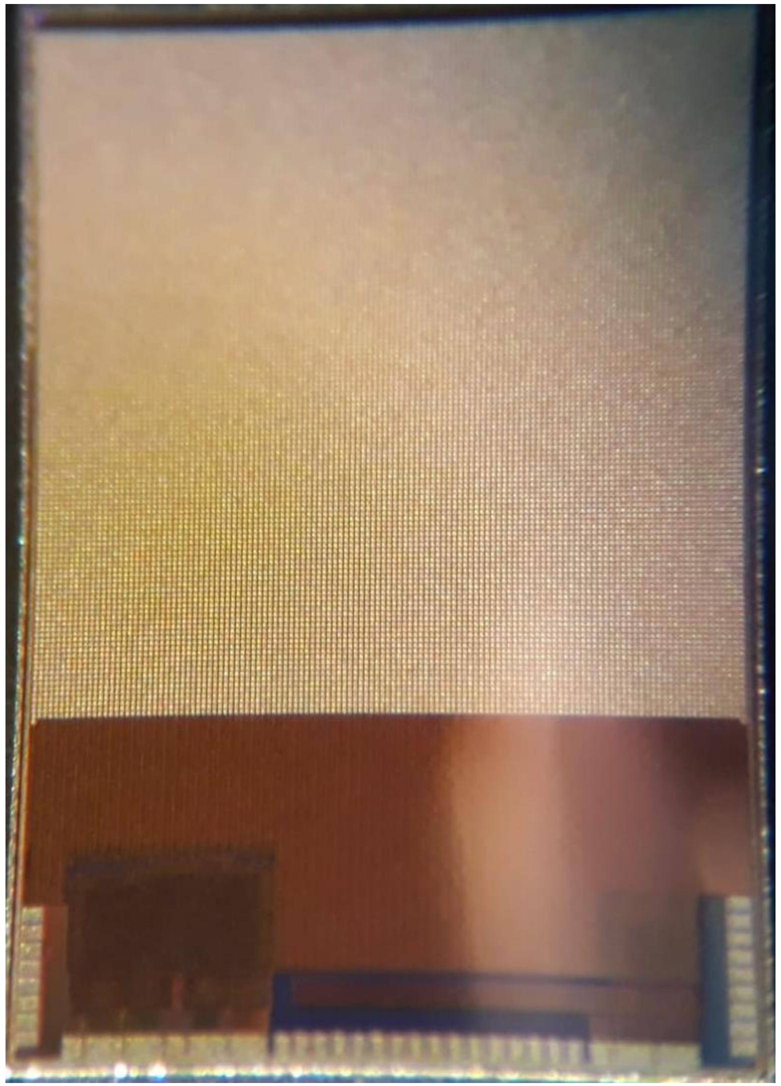
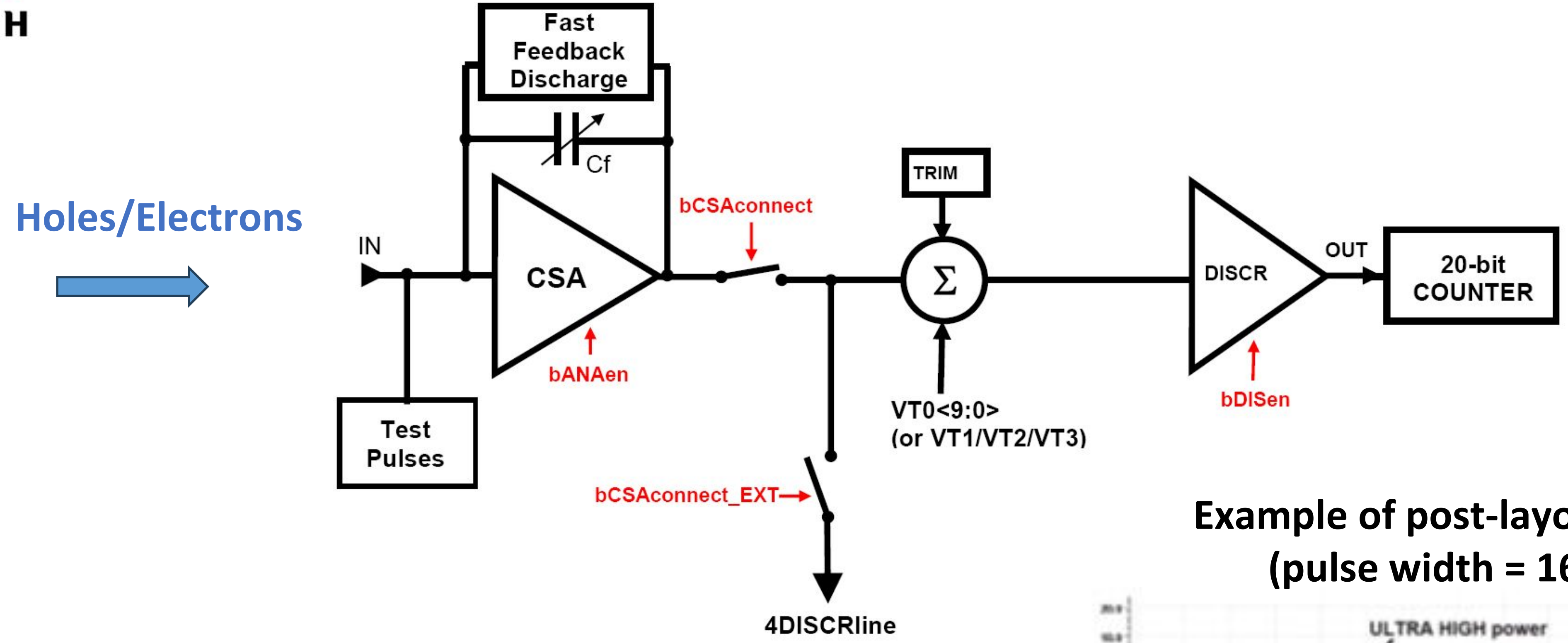
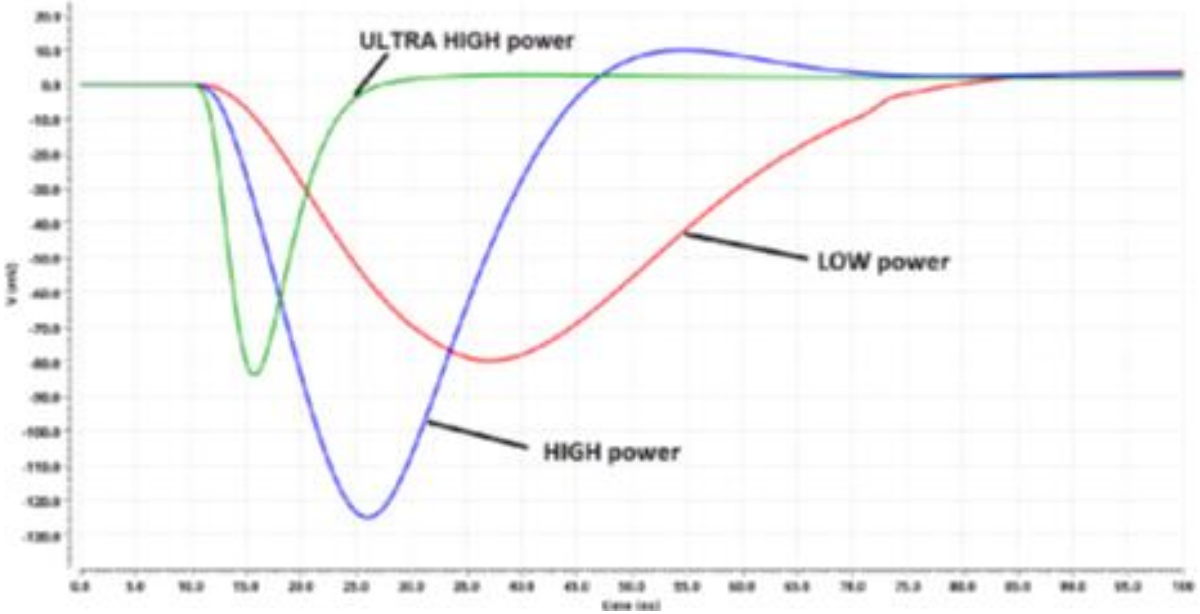



Photo of PIX25

# Single pixel architecture
## (can operate with Si, GaAs, CdTe, CZT detectors)

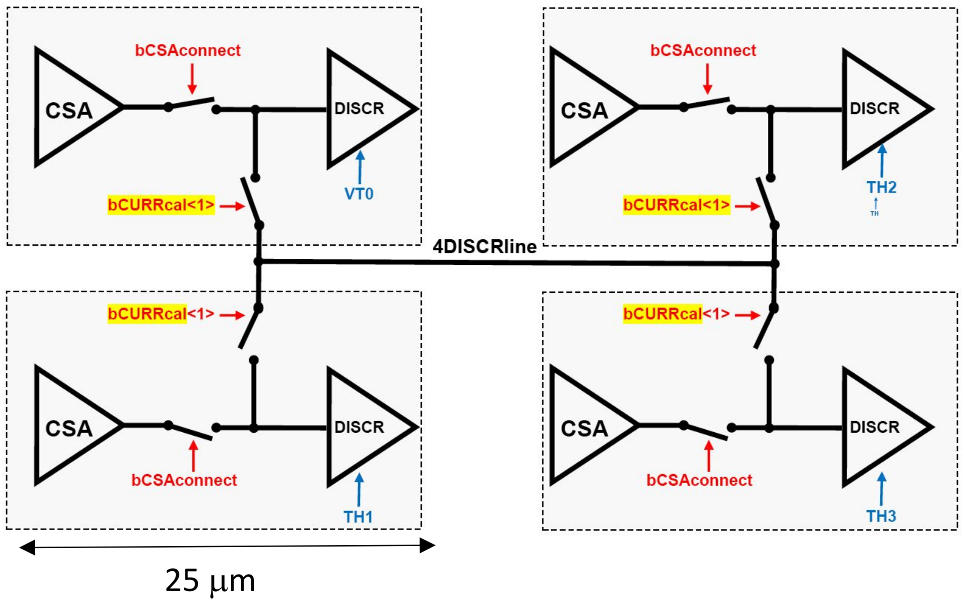


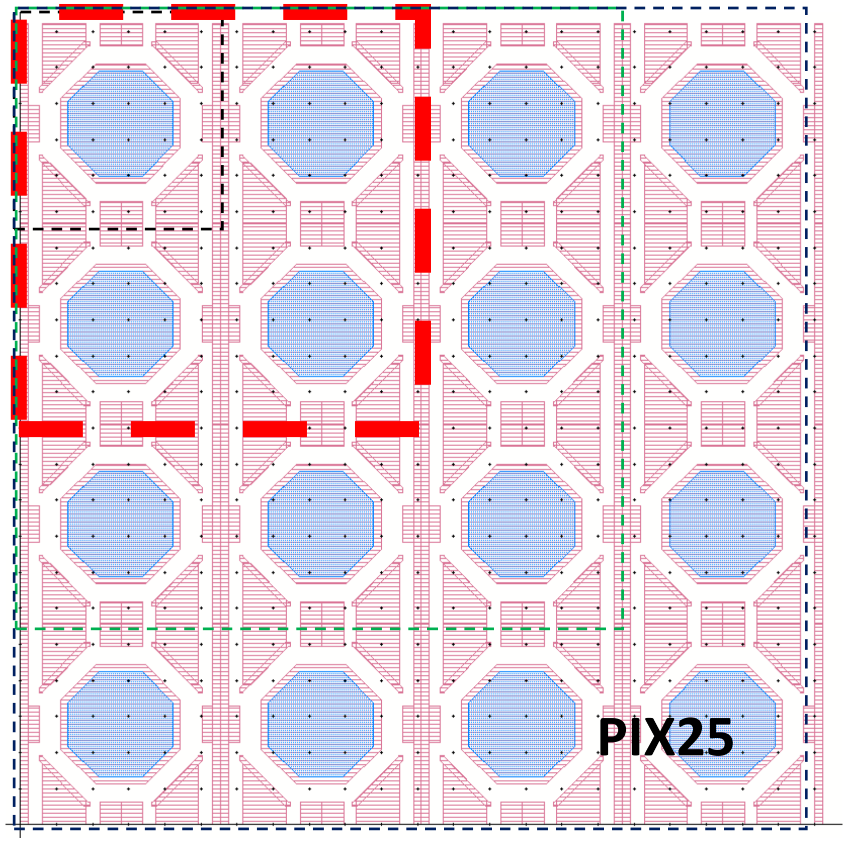

**Example of post-layout simulation - holes**
**(pulse width = 16 ns/34 ns/66 ns)**



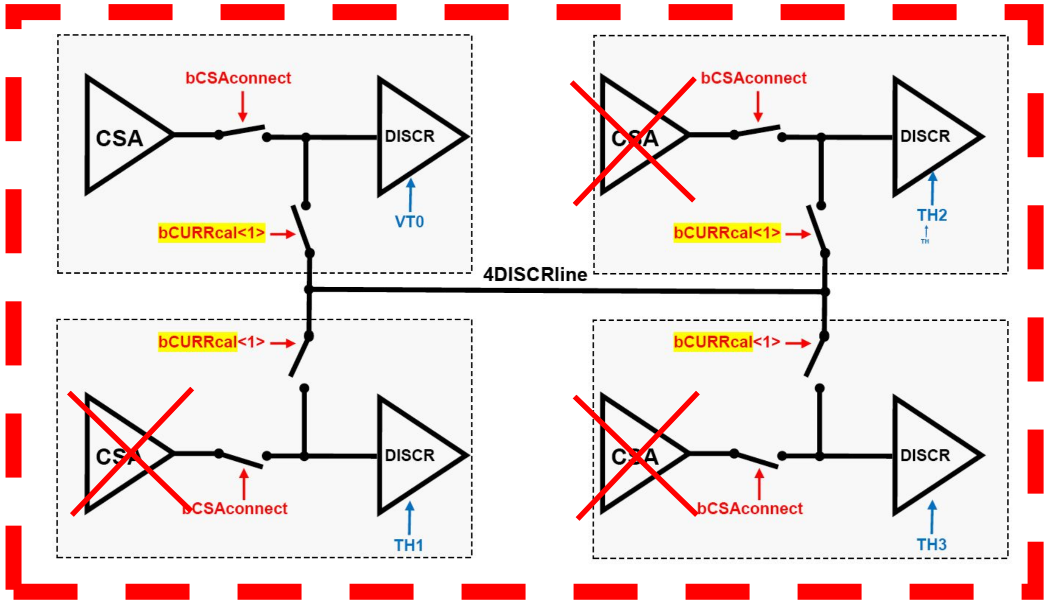
# ROIC pixel pitch 25 µm

## but can be bump-bonded to detector with different pixel pitch (25/50/75/100 µm)




**Example 50 µm pitch**




**Power control & analog pixel disable:**

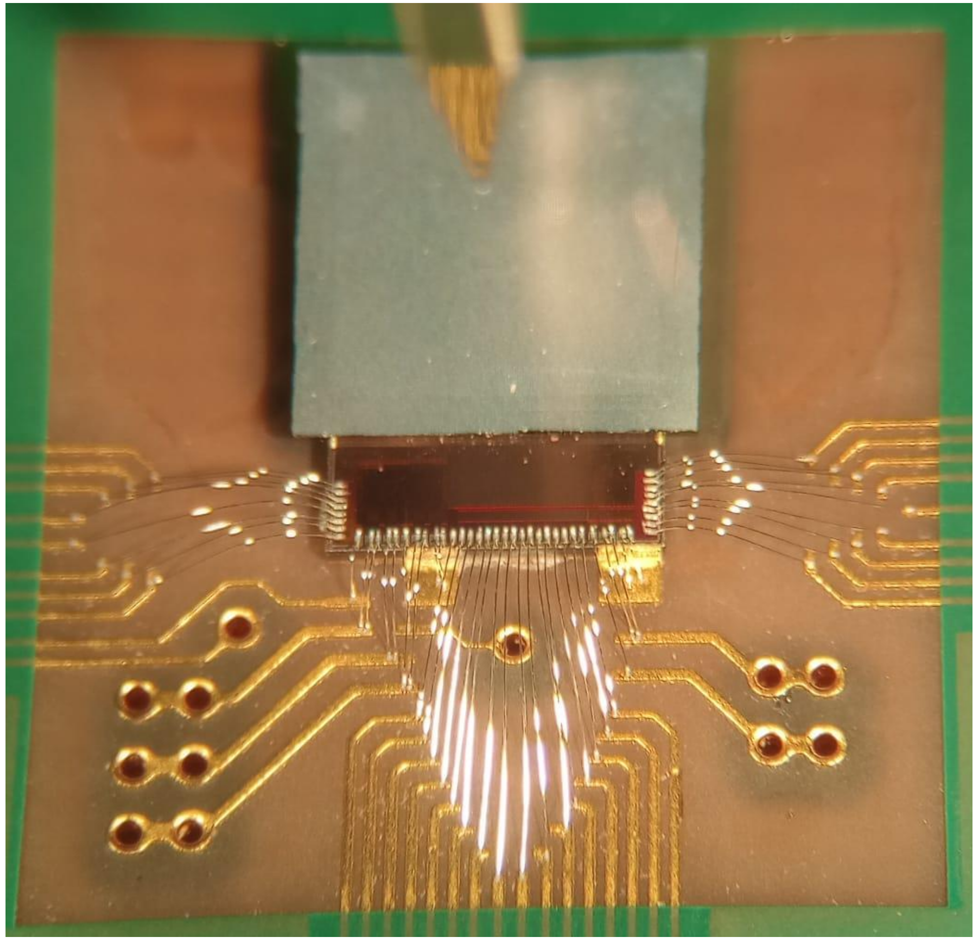
**PIX25 pixel pitch:**

**25 µm**
**50 µm**
**75 µm**
**100 µm**

**can be set by detector's pixel pitch**

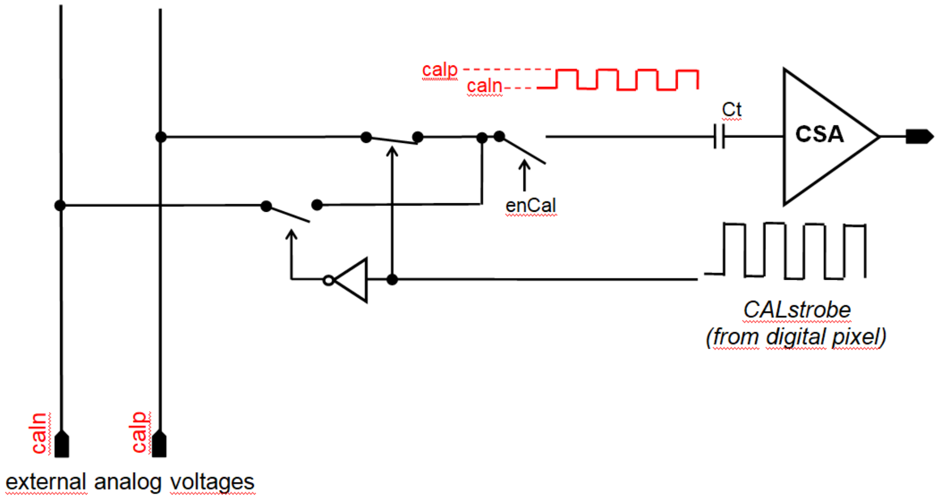
**For 25 µm pitch – 1 discrimiantor**
**For 50/75/100 m pitch – 1/2/3/4 discriminator**

# ROIC bump-bonded to Si sensor (150 µm thickness and 25 µm pitch)



# Charge injection circuit – two different solutions implemented

## Standard solution



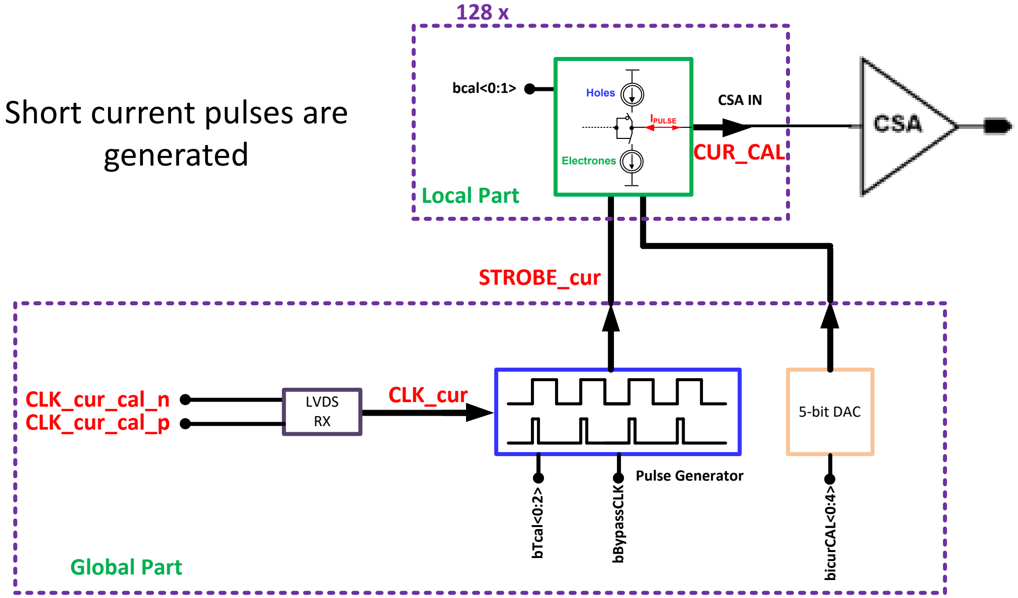

**Current IN**

**Current OUT**

**High count-rate performance can not be tested**

## New solution – current pulses of single polarity

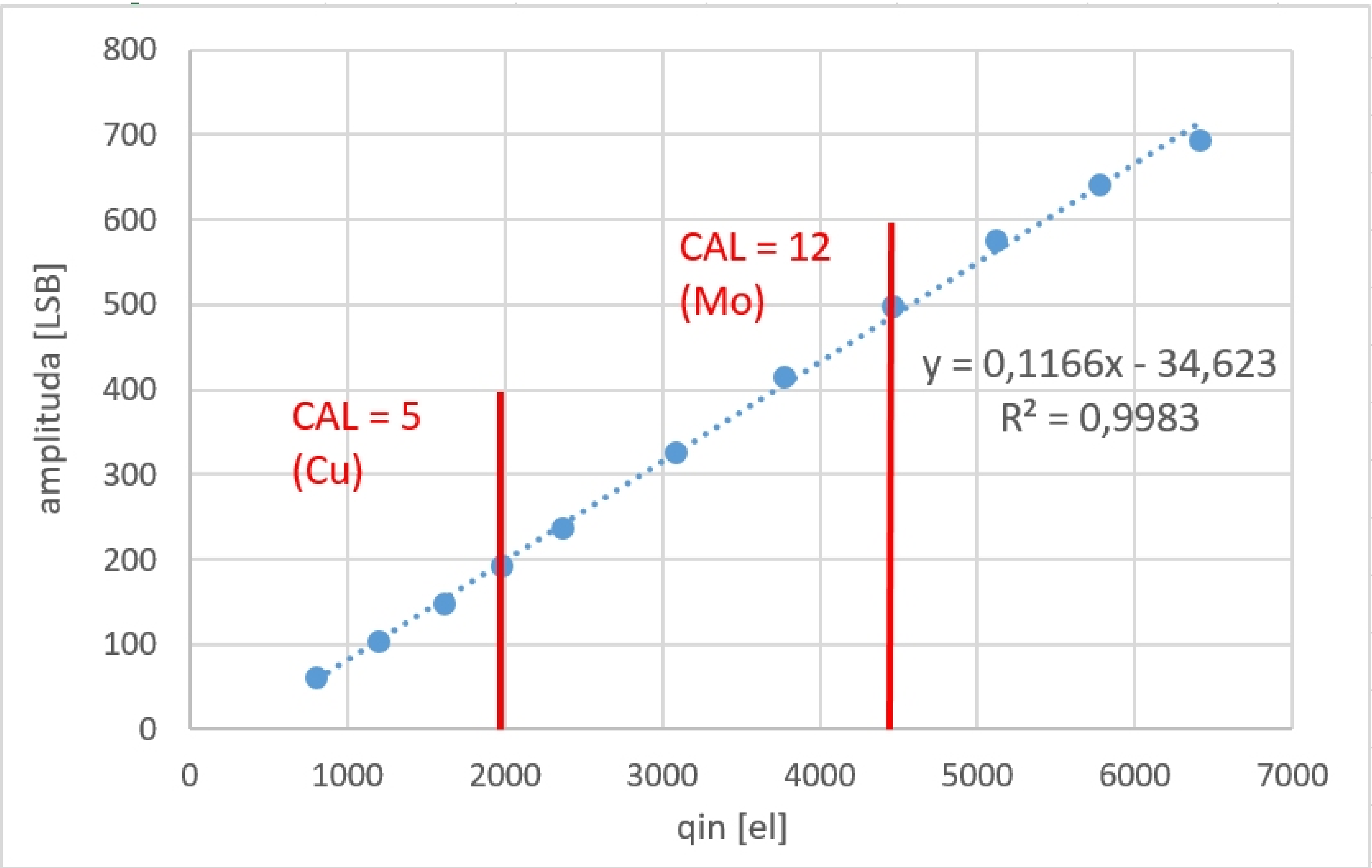
Short current pulses are generated



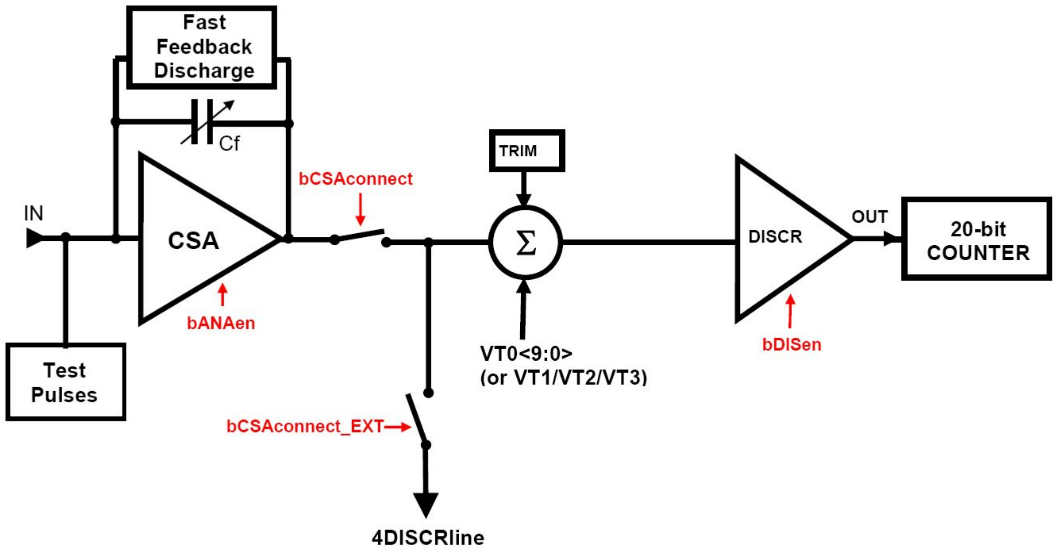

**Current IN**

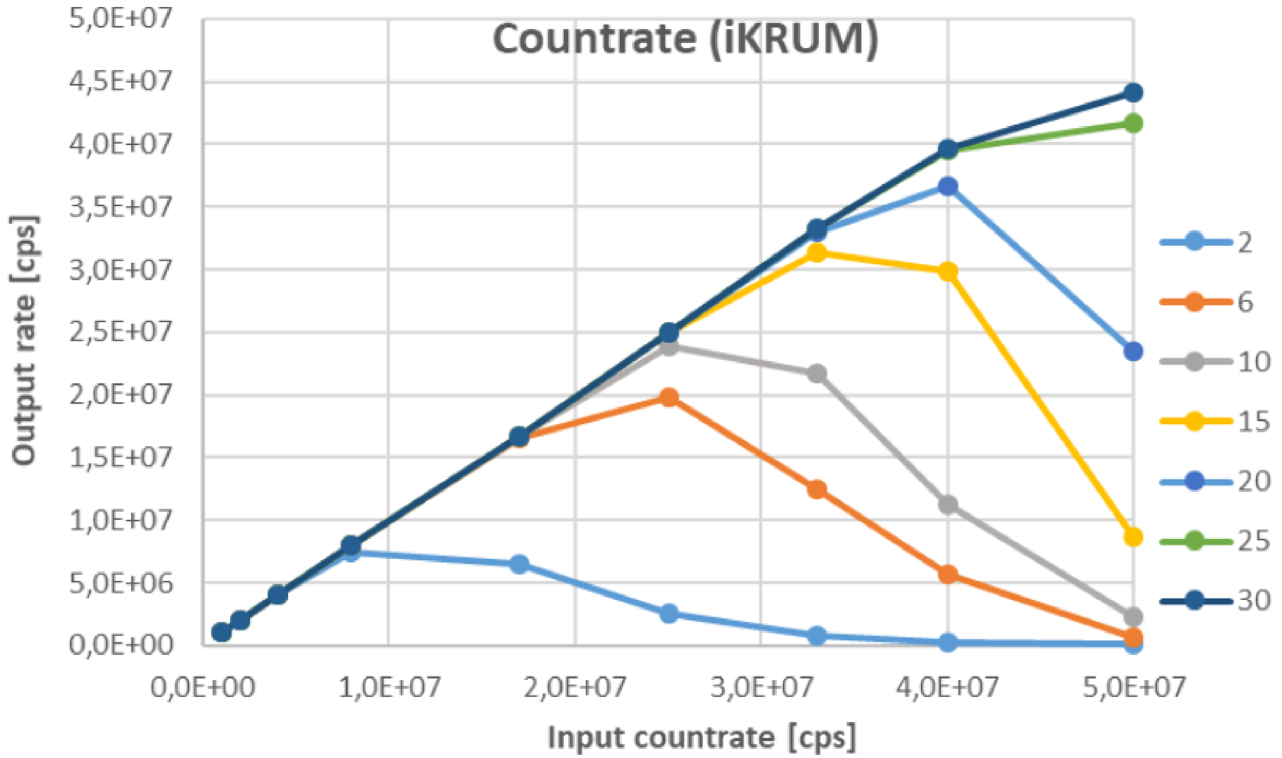
**High count-rate performance can be tested**

# Linearity measurements with test pulses



# Count-rate measurements with current pulses of single polarity

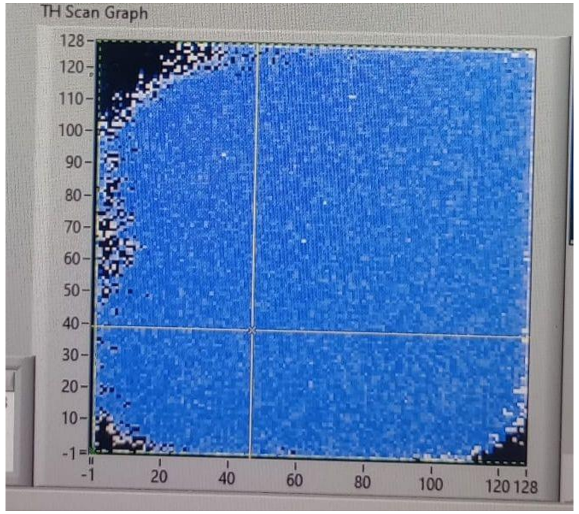


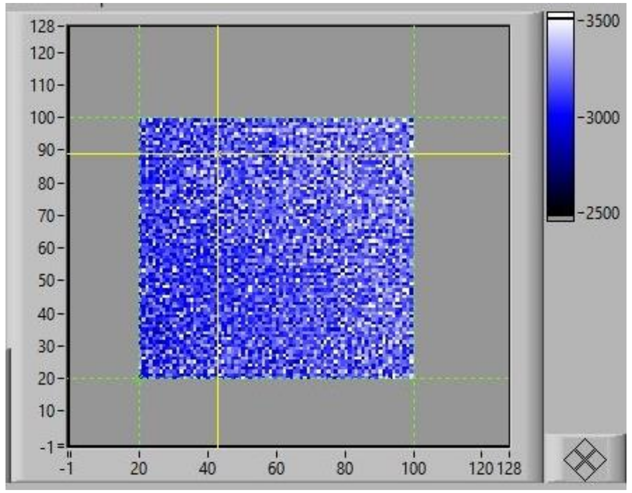

| Mode | Power/pixel [μW] | iKRUM range [LSB] | ENC [el.] | Count-rate [MHz/pixel], 10% loss – pulses with equal time distance |
|---|---|---|---|---|
| High Power | 19.1 | 6 - 30 | 100 - 128 | 18 - 46 |
| Low Power | 12.6 | 4 - 20 | 105 - 128 | 18 - 40 |
| Very Low Power | 7.7 | 4 - 20 | 117 -155 | 17 - 40 |

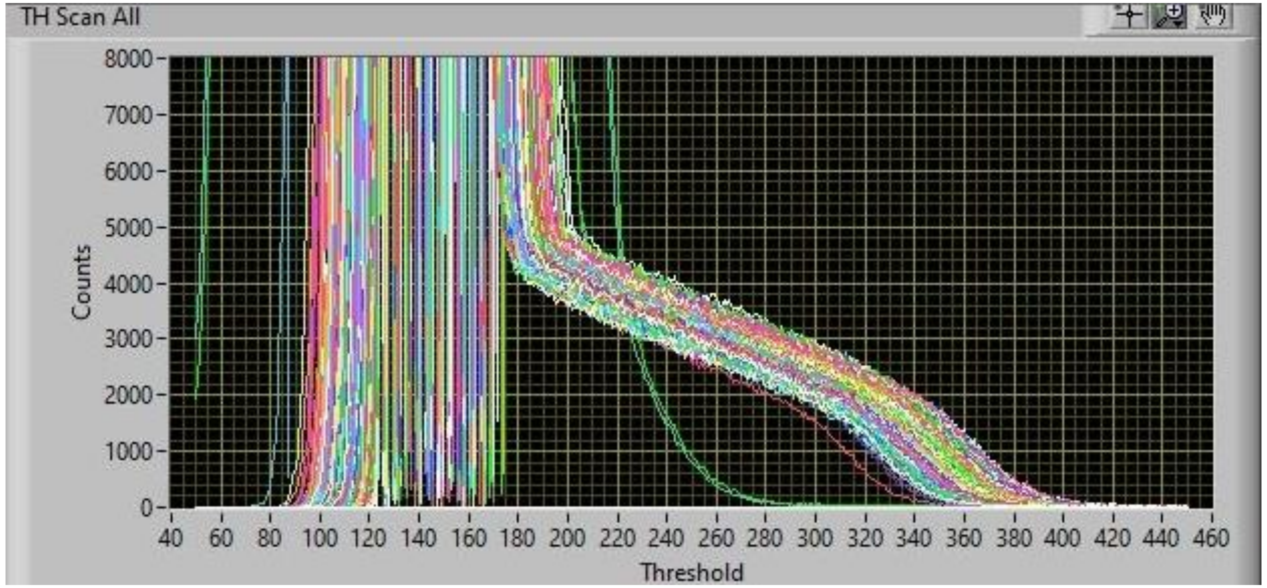
# The tests with X-rays (Cu line, 8.4 keV)
# Si sensor: pitch 25 µm, thickness 150 µm

**All pixel**




**Central part**

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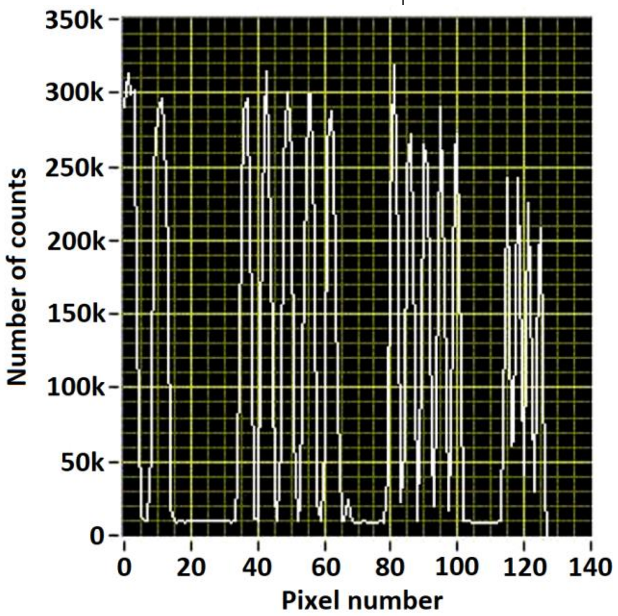
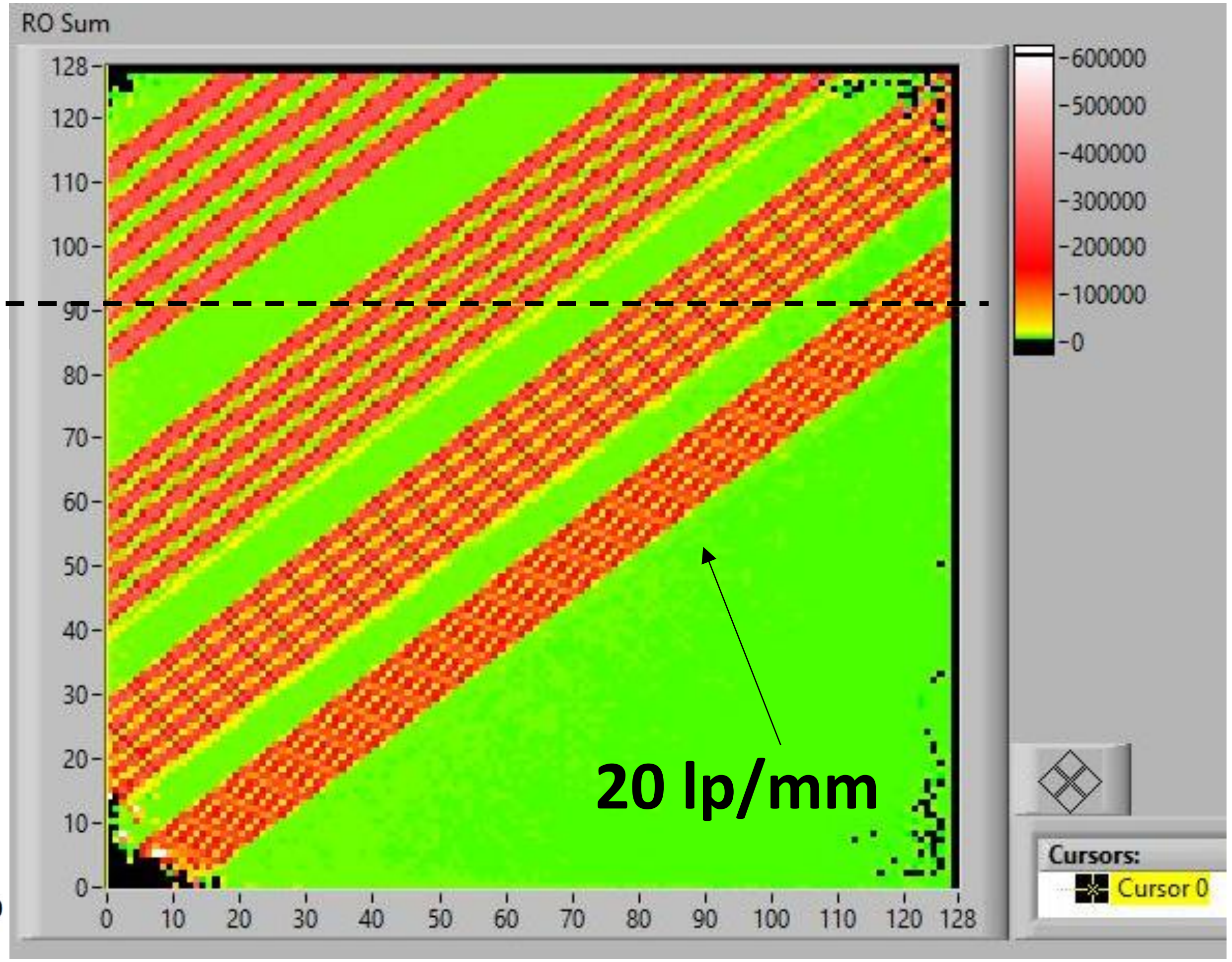
# Position resolution measurements with test pattern (Pattern type 18d: 0.5 – 20 lp/mm, distance 5 mm from the detector)

(cross-section)



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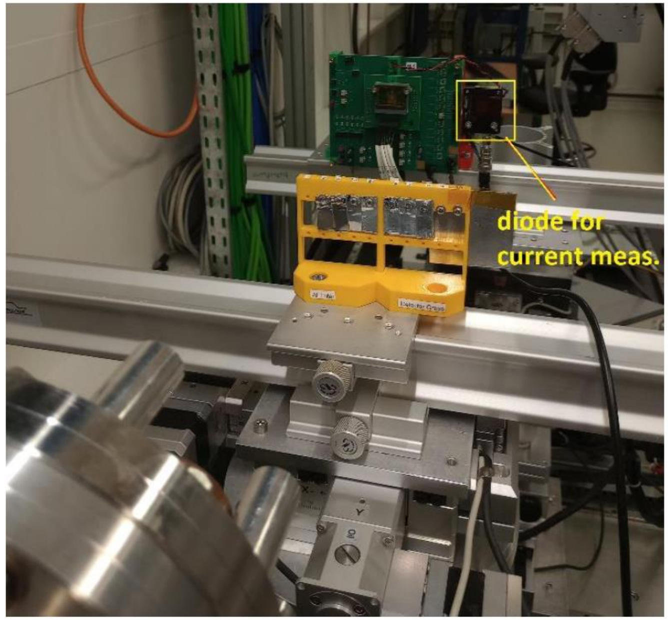
# Count-rate measurements in Synchrotron SOLEIL – France

During measurements photons energy was set to 12 keV (but it also had a 3rd harmonics energy of 36 keV), and their intensity was regulated by the thickness of Al filters - 9 measurements points = 8 Al foils different thickness and one with no foil (direct beam directed to the module). A reference diode was used for determining the “currents” (related to the beam flux) for each foils’ positions, which we used in the x-axis of count-rate performance characteristics.




**Many thanks to Arek Dawiec and Marie Andra from SOLEIL**

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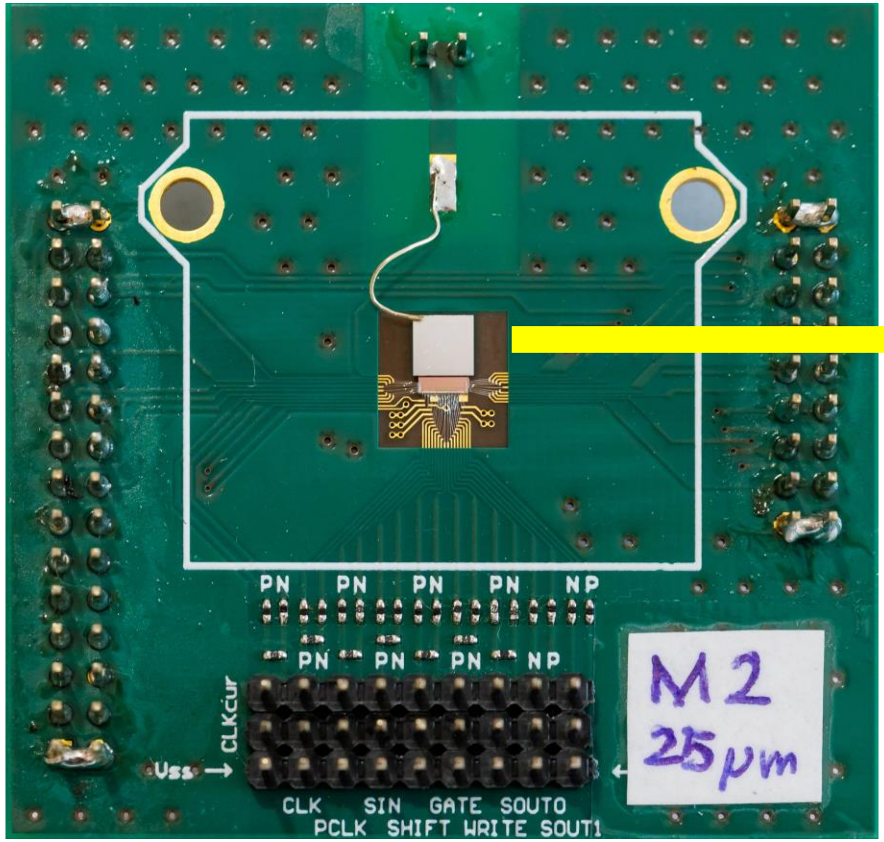
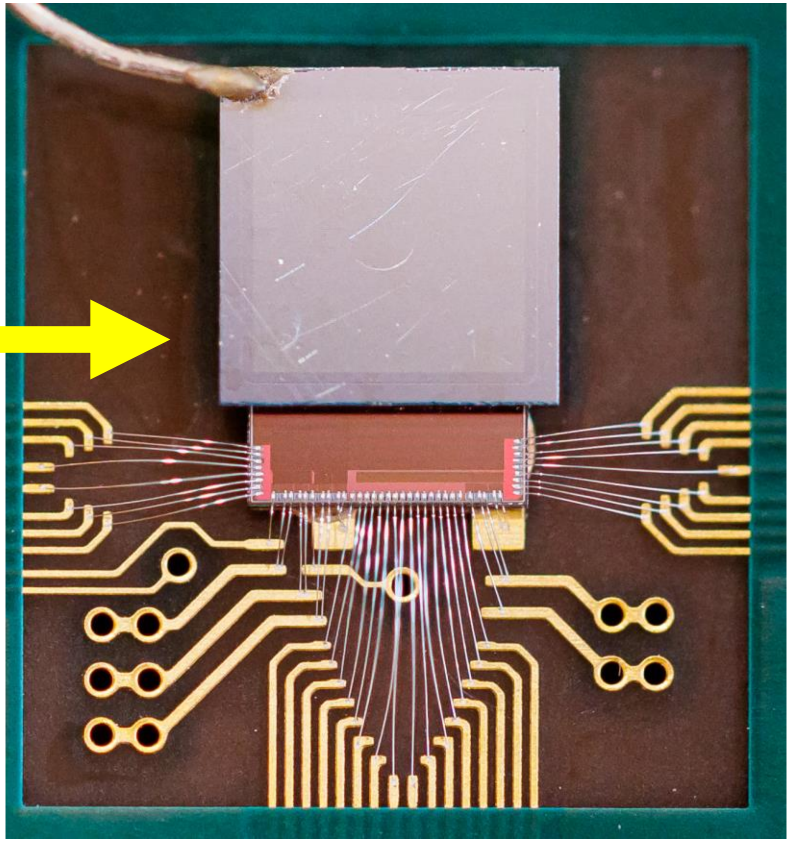
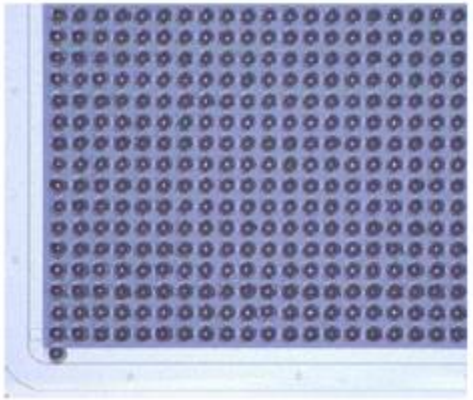
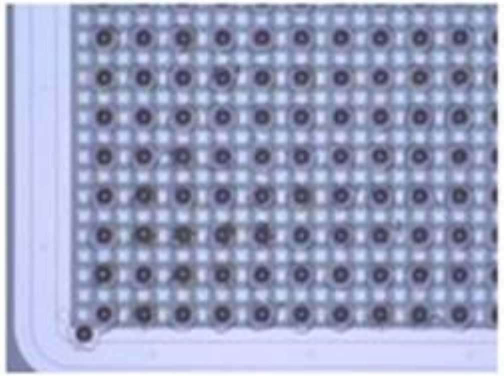
# Silicon sensor - thickness 450 µm (different bump-bonding scheme)



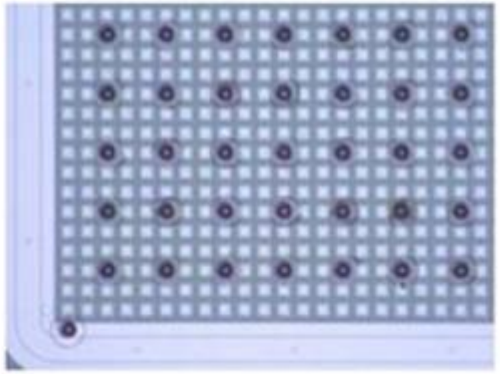





25µm – bump pitch



50µm – bump pitch

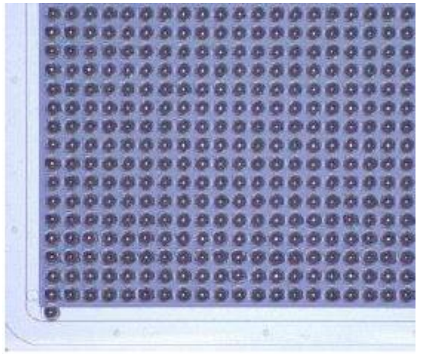


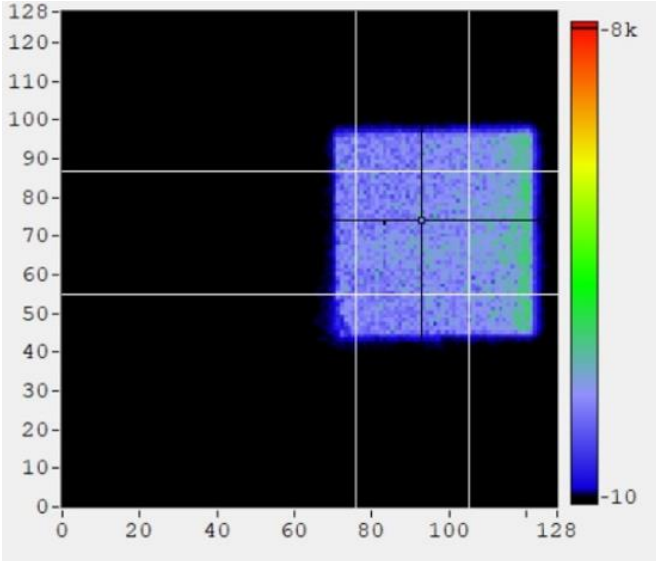
75µm – bump pitch

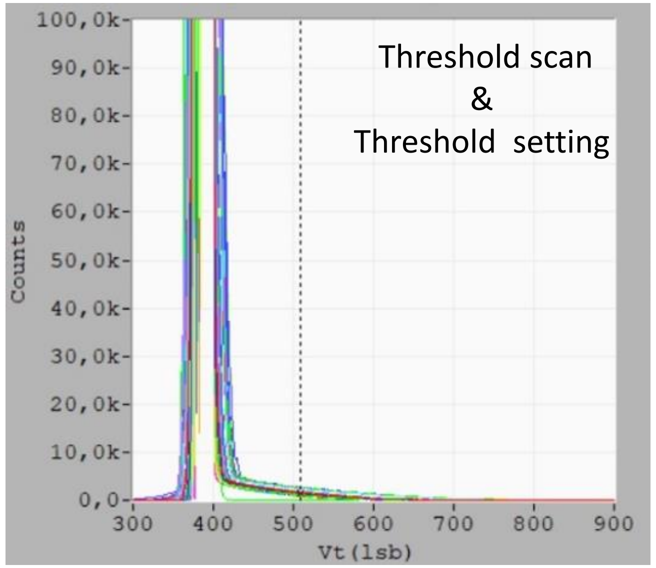
# Module with Si detector with bump-bonding pitch 25 µm (chip settings iKRUM=14)

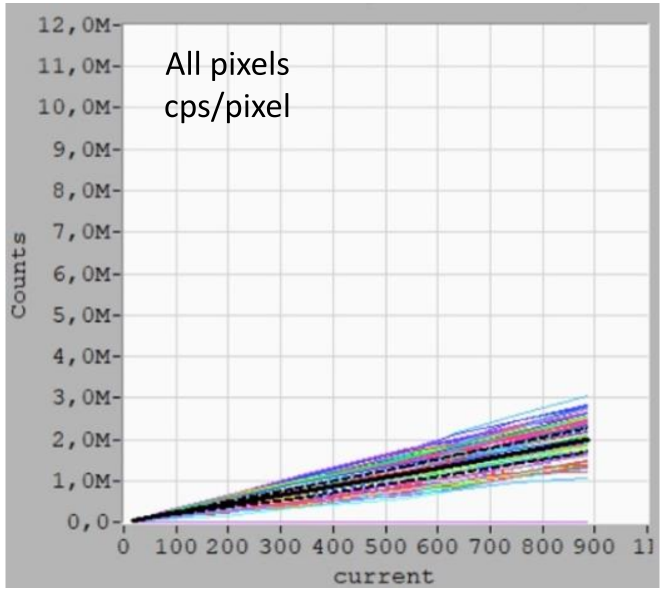
## Measurements

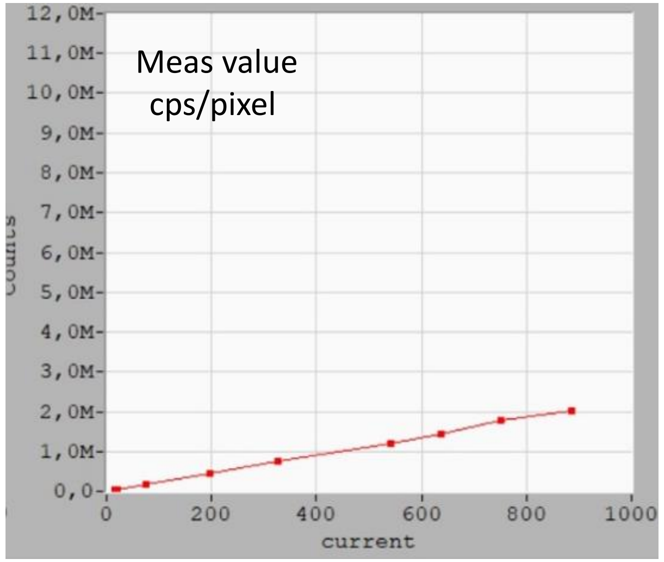
bump pitch 25 µm





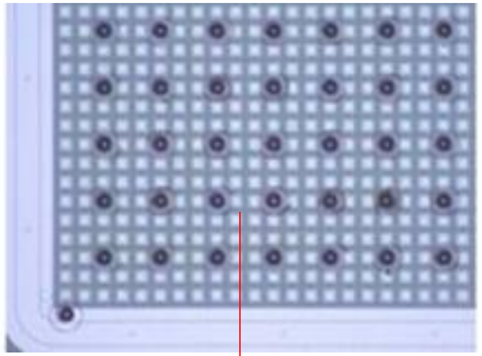




**We were not able to saturate the count-rate - bump-bonding pitch 25 µm**

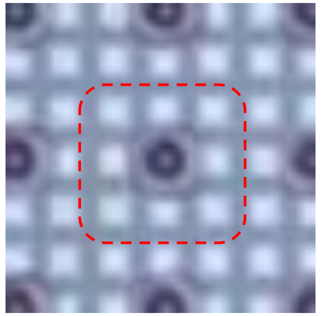
# Module with Si detector with bump-bonding pitch 75 μm (chip settings iKRUM=14)

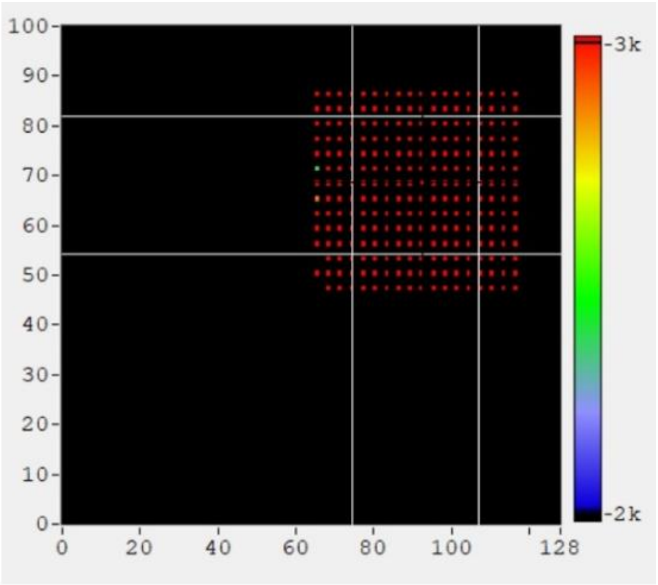
## Measurements

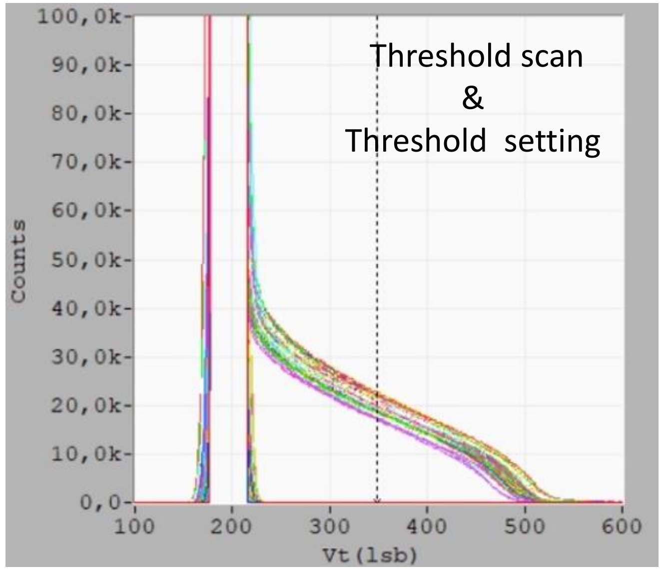
bump pitch 75 μm

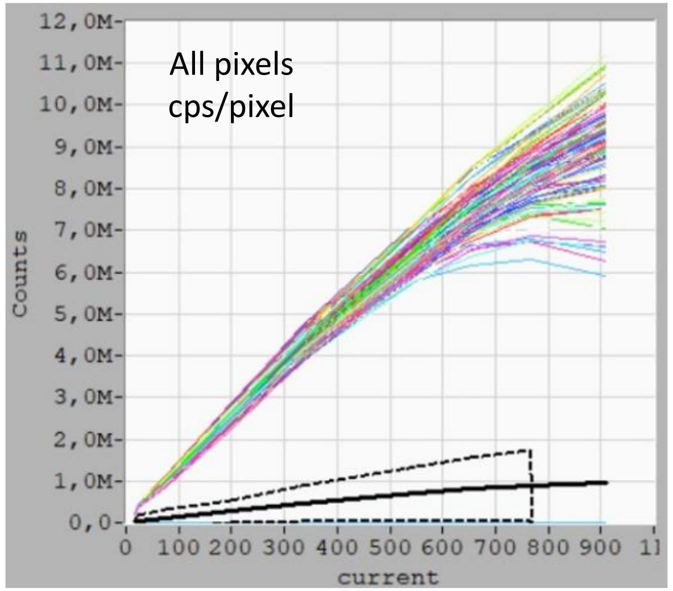


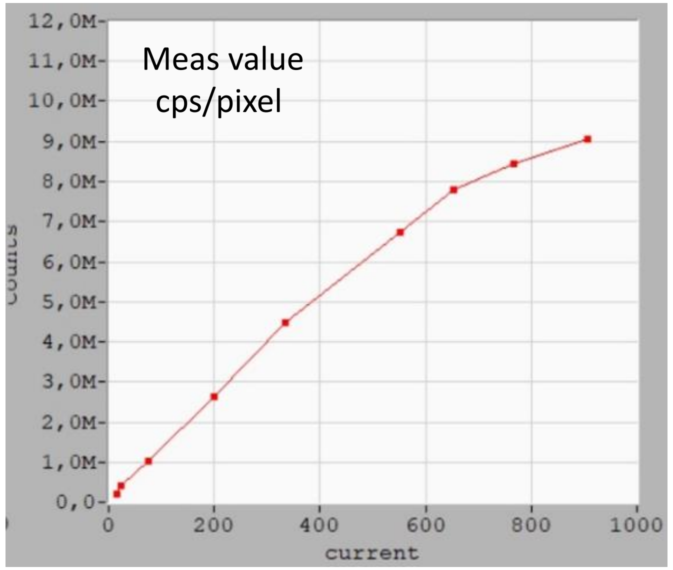
zoom







# Summary of PIX25 IC

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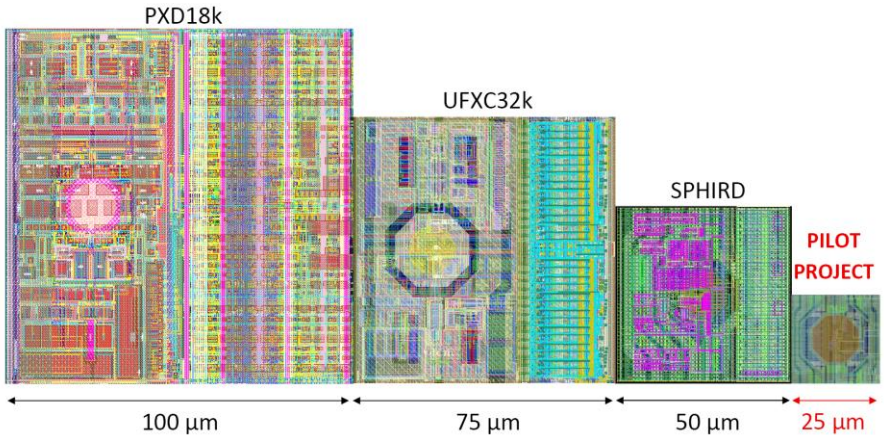
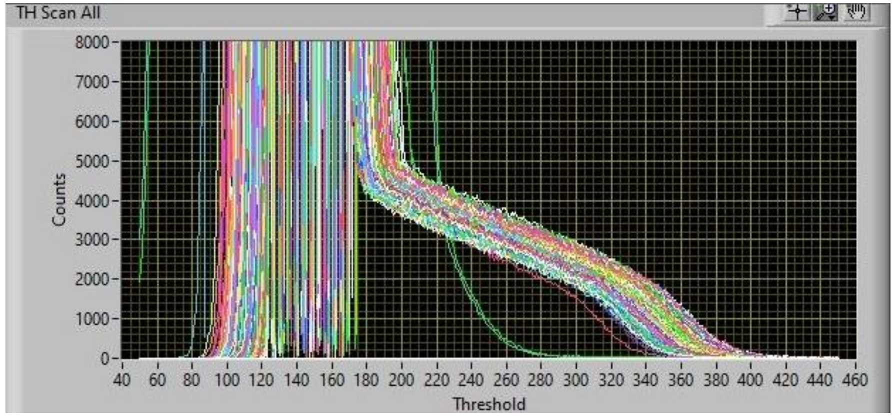
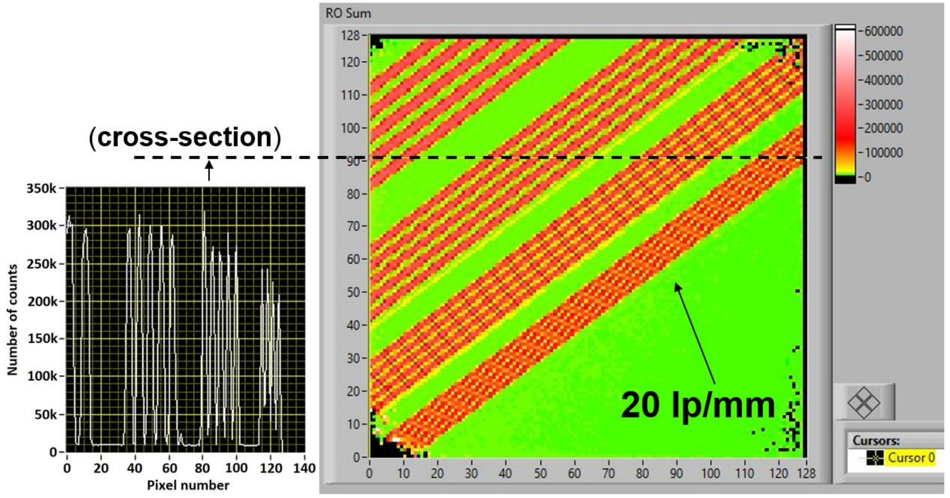
### Small pixel size – 25 μm



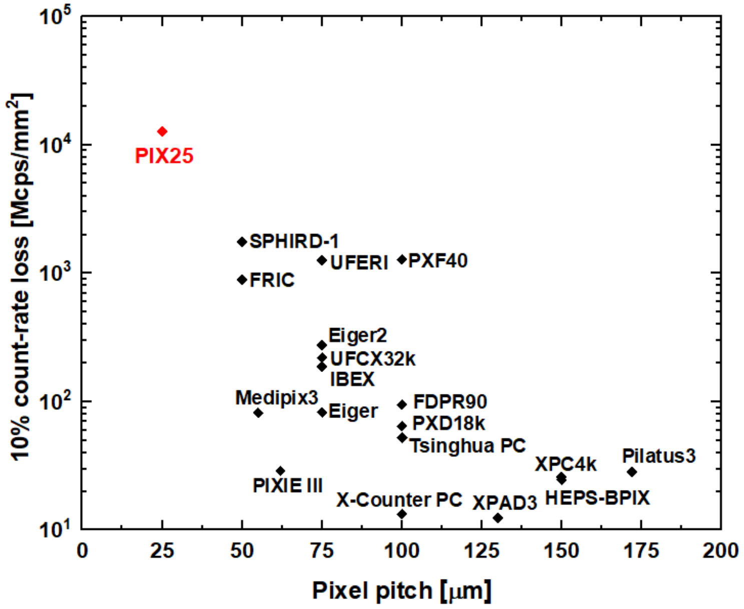

### Good energy resolution and pixel to pixel uniformity – below 8 keV lines




### Good spatial resolution – 20 lp/mm



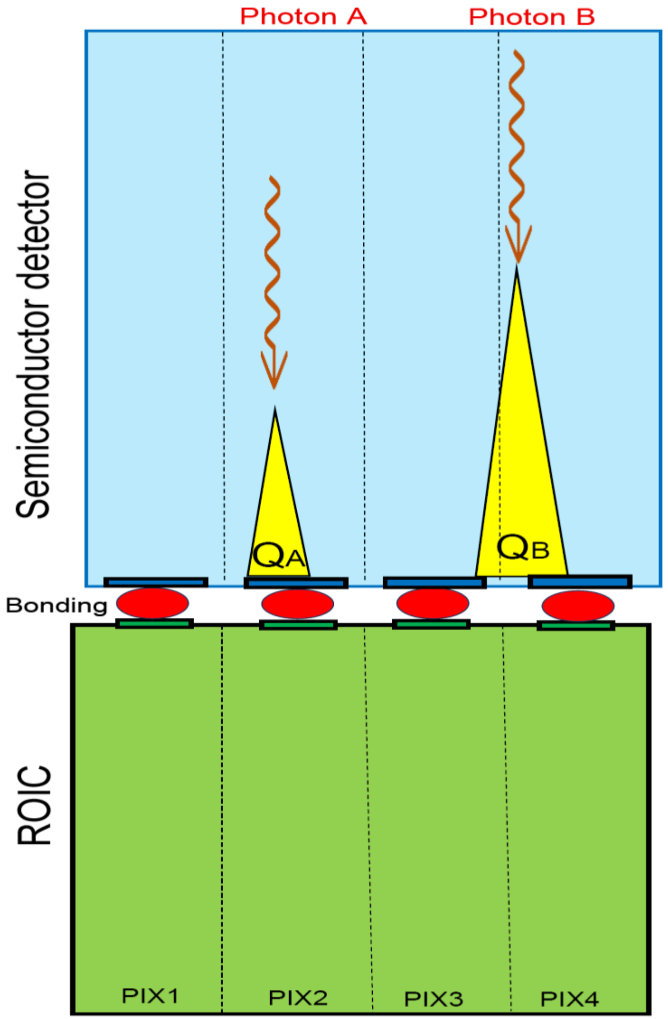

### Very high count rate - 12 Gcps/mm²




This work has been supported by the National Science Center (Poland) under project no. 2023/51/B/ST7/01782.

# Next step - question:

How can one balance the need for sufficient X-ray absorption in the sensor material with the challenges of charge sharing in small-pixel detectors?



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How can one balance the need for
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