A 92k SPAD Time-Resolved Sensor in 0.13µm CIS Technology for PET/MRI Applications

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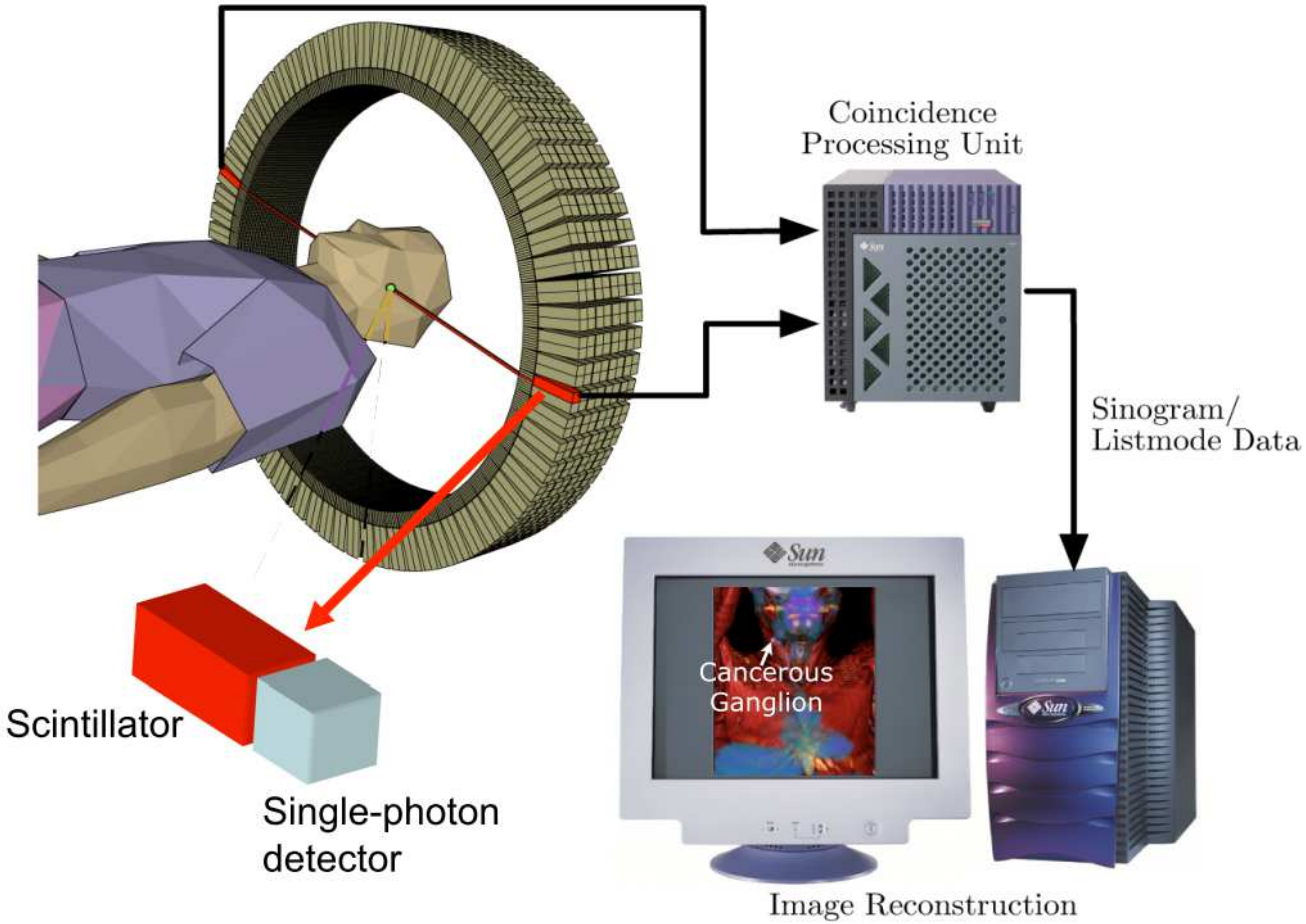
PET Imaging Background

- MRI/CT:
  - Provide *structural* information
- PET:
  - Provides *functional* information
  - Patient administered with radiotracer
  - Areas of high metabolic activity visible: applications in oncology & neurology etc.
- Goal:
  - Enabler for multi-modal imaging

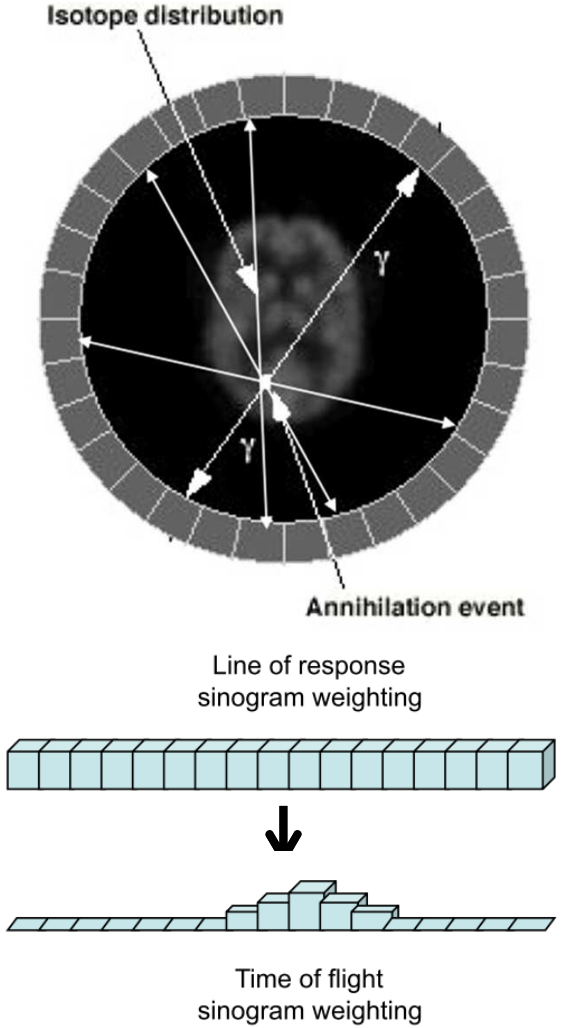
Goal: Simultaneous Combined PET+MRI

- Several advantages over PET+CT:
  - MRI does not involve X-ray dose.
  - MRI provides improved soft tissue contrast.
- However, not cost effective at present.
  - Magnetic field of MRI scanner incompatible with current PET systems.

PET Imaging Background



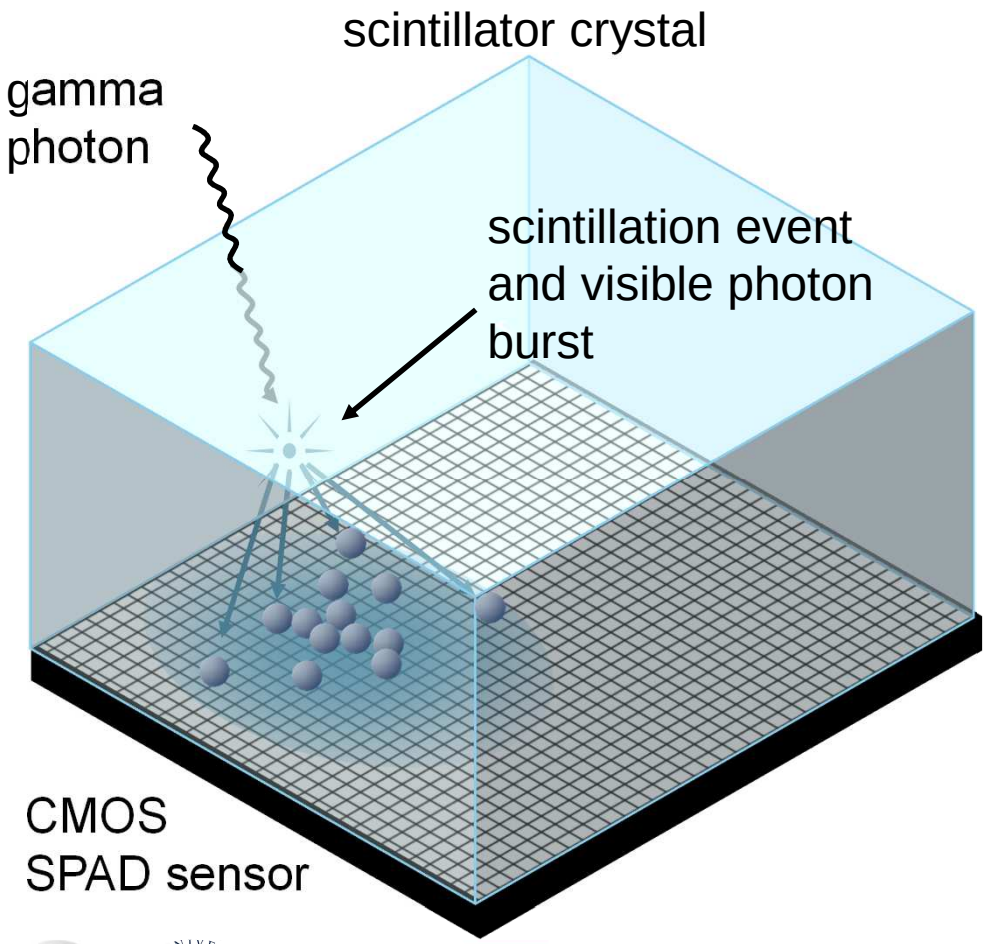
Source: Sun

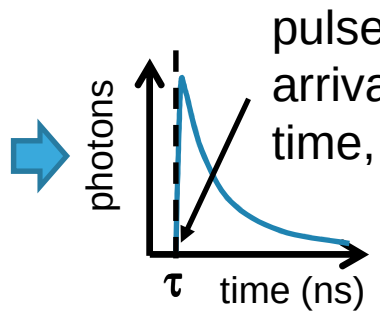


Source: Ramsey Badawi, University of Washington

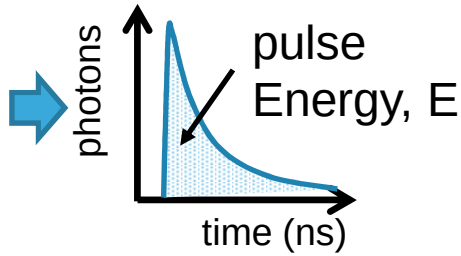
Data Extraction in a PET Module

- Each time a Gamma photon strikes the scintillator...





Coincidence detection



Rejection of low-energy scattered gamma photons

pulse spatial position x-y

Image reconstruction

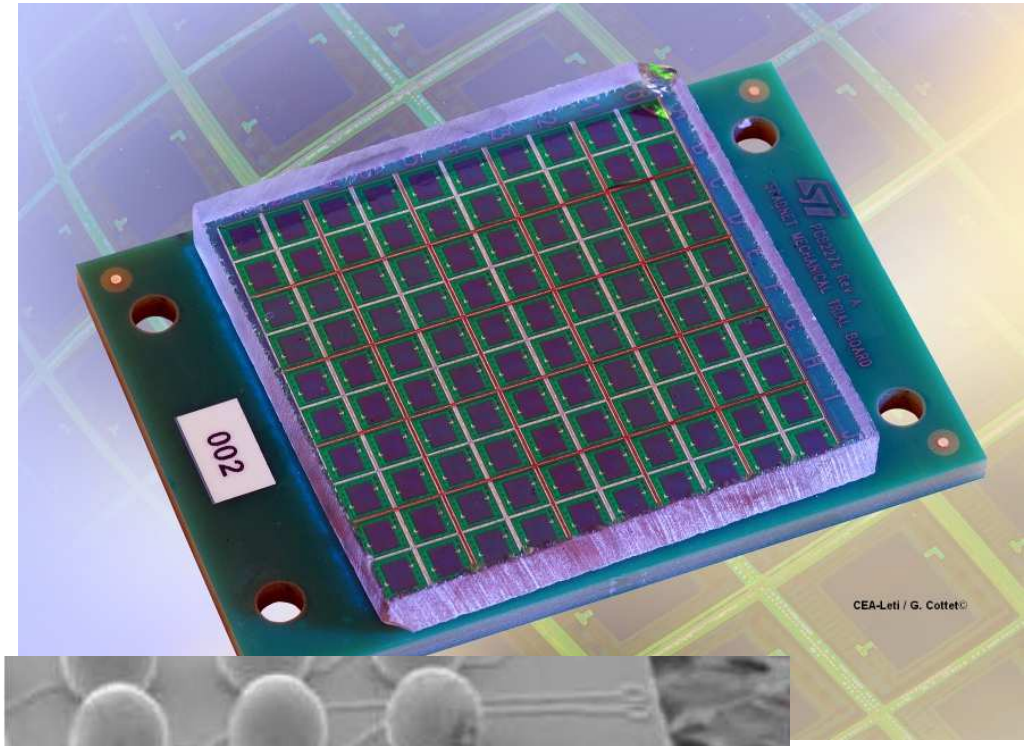
Typical PET System Detectors

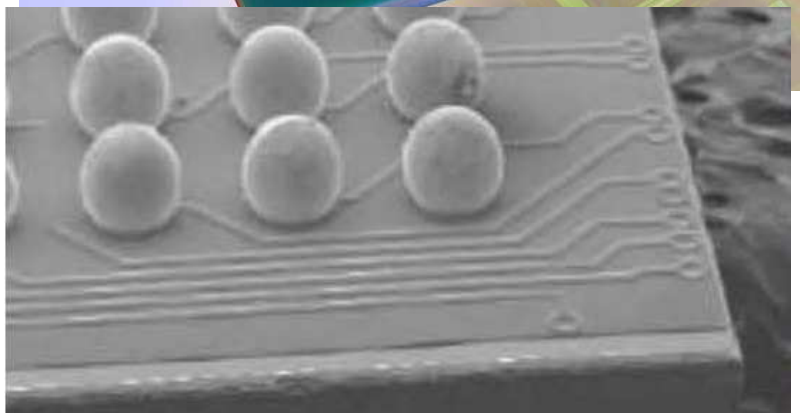
- Photomultiplier tubes (PMT)
  - Classic detector of choice
  - Bulky, fragile…
  - Incompatible with magnetic fields
- Avalanche photo-diodes (APD)
  - Analog gain – sensitive to voltage/temperature
- Silicon-Photomultipliers (i.e. SPAD arrays):
  - Analog (aSiPM)
  - Digital (dSiPM) – emerging trend

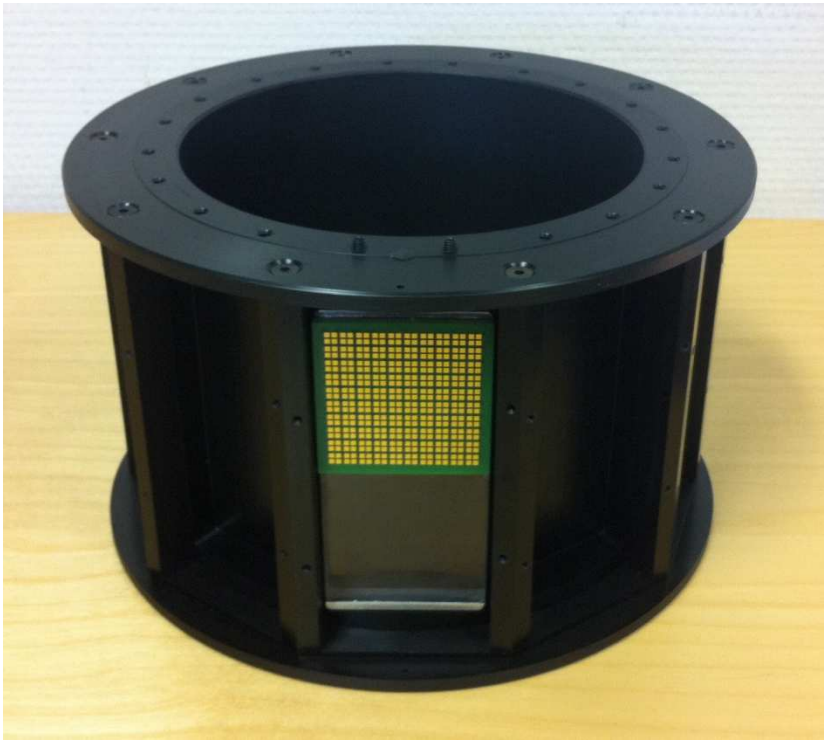
The SPADnet Sensor Concept

The design challenge - a new sensor which:		The solution:
• Is MRI compatible	→	• Silicon based
• Is mass-manufacturable at low cost	→	• Standard CMOS imaging process
• Potential to extract *more information* per photon	→	• Leverage ability to integrate time-stamping circuits and logic.
• Meets existing PET system requirements	→	• Sensitive fully-digital SPAD array

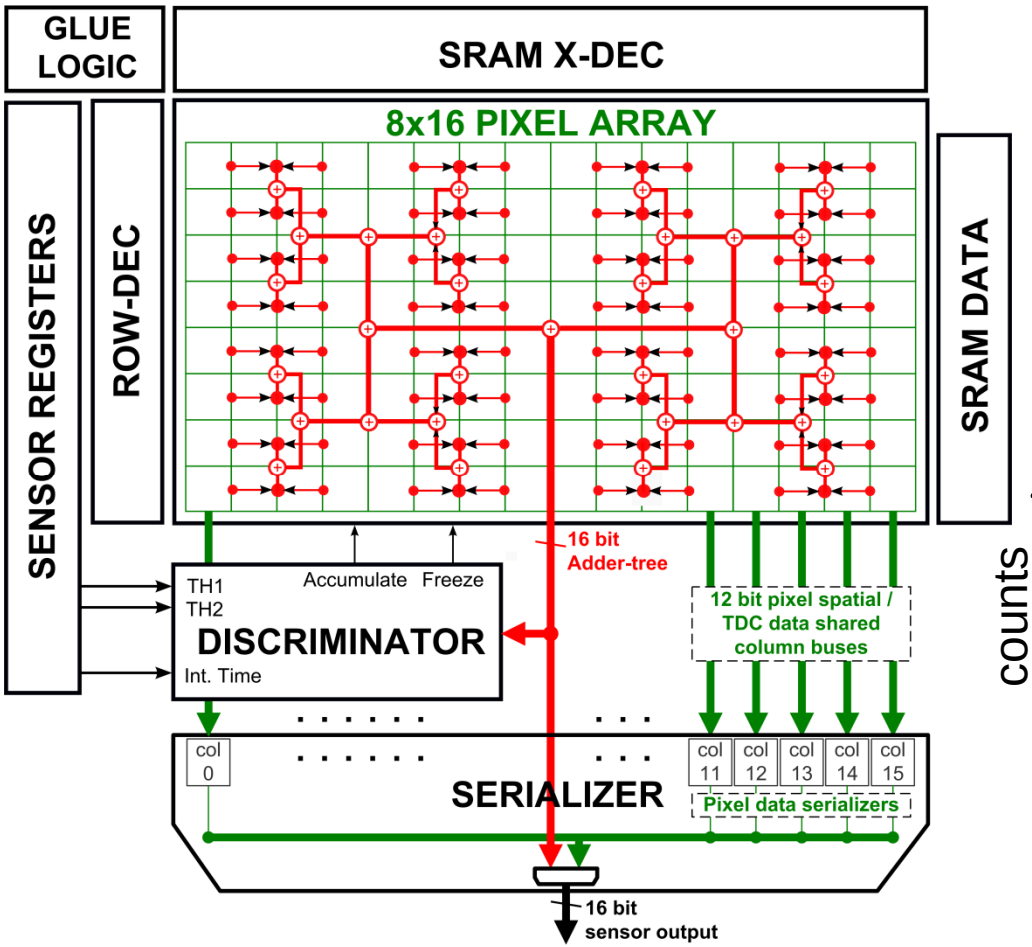
The SPADnet Sensor Concept



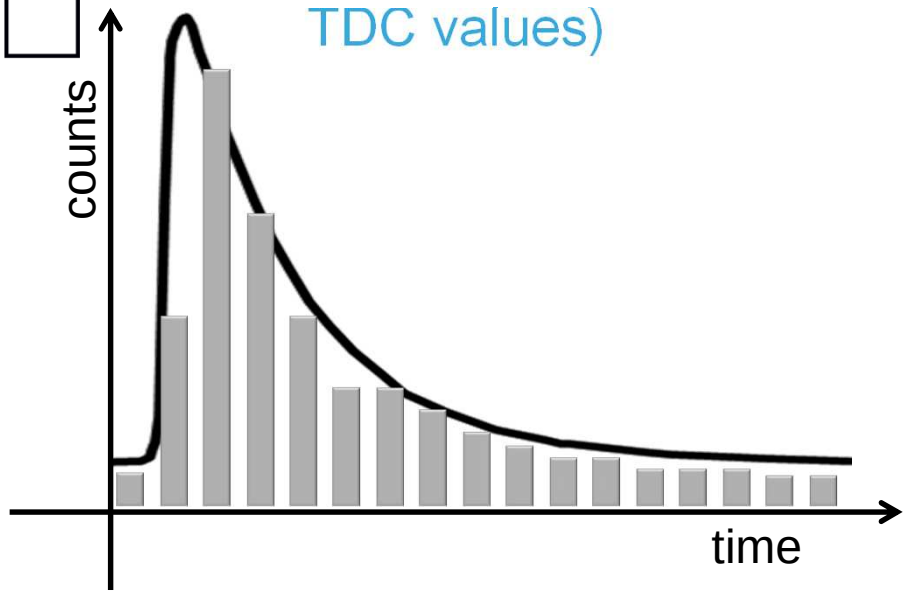




Sensor Architecture



- Two operating modes:
  - Real time energy histogramming
  - Pixel data readout (spatial image data & TDC values)



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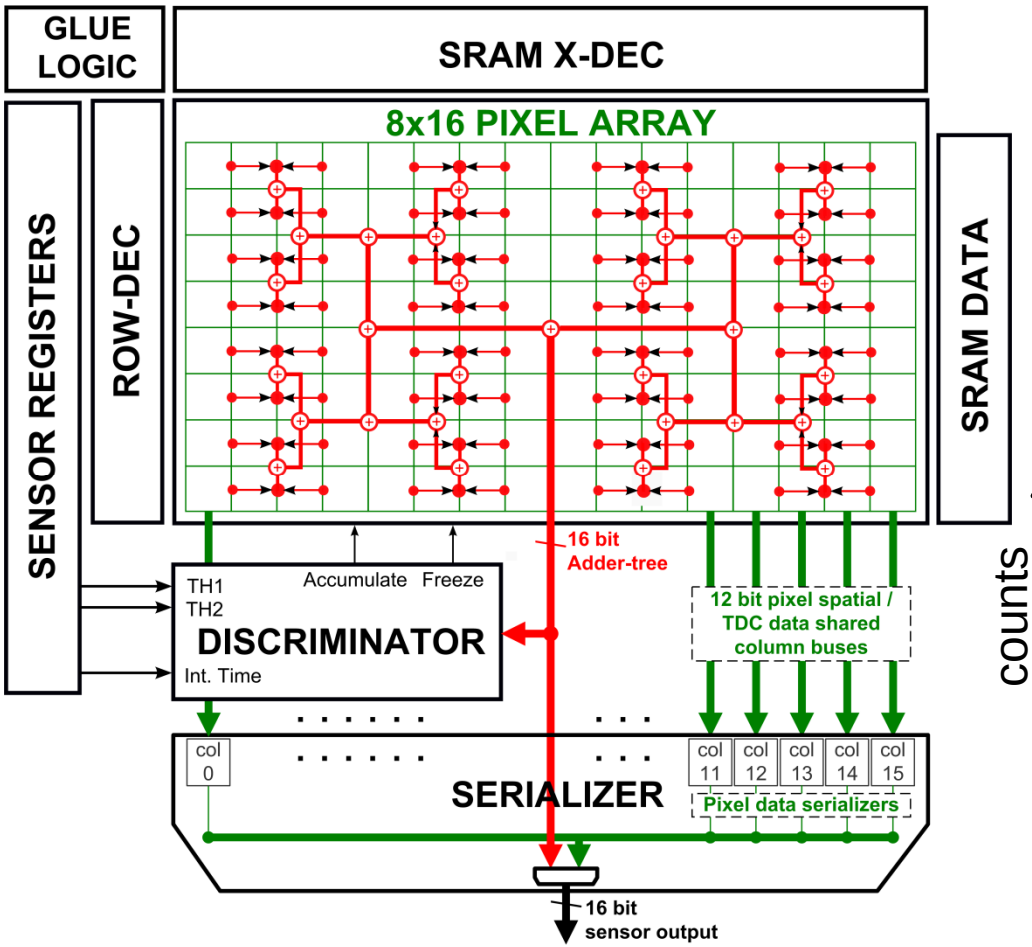
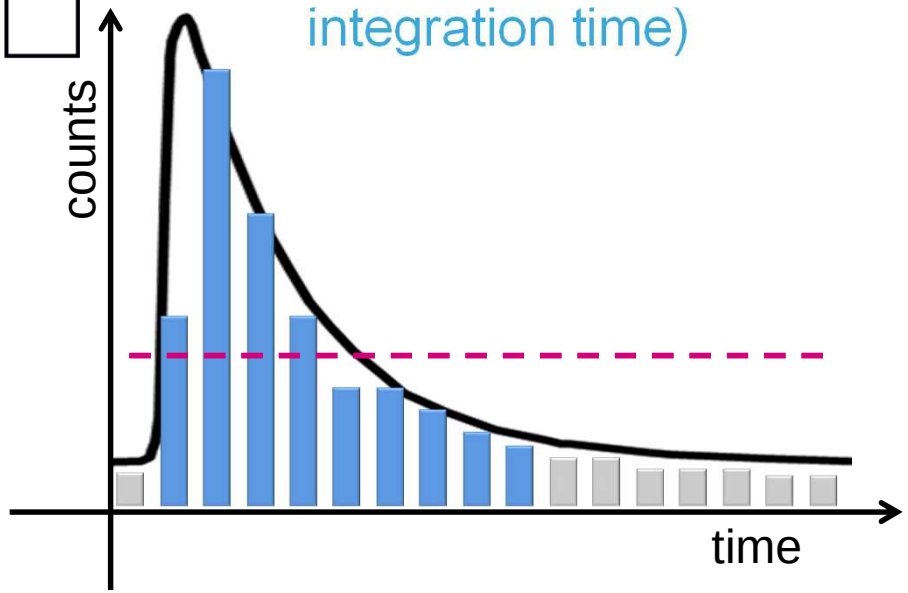


- On-chip discriminator:
  - Recognises valid events
  - Controls integration (programmable integration time)



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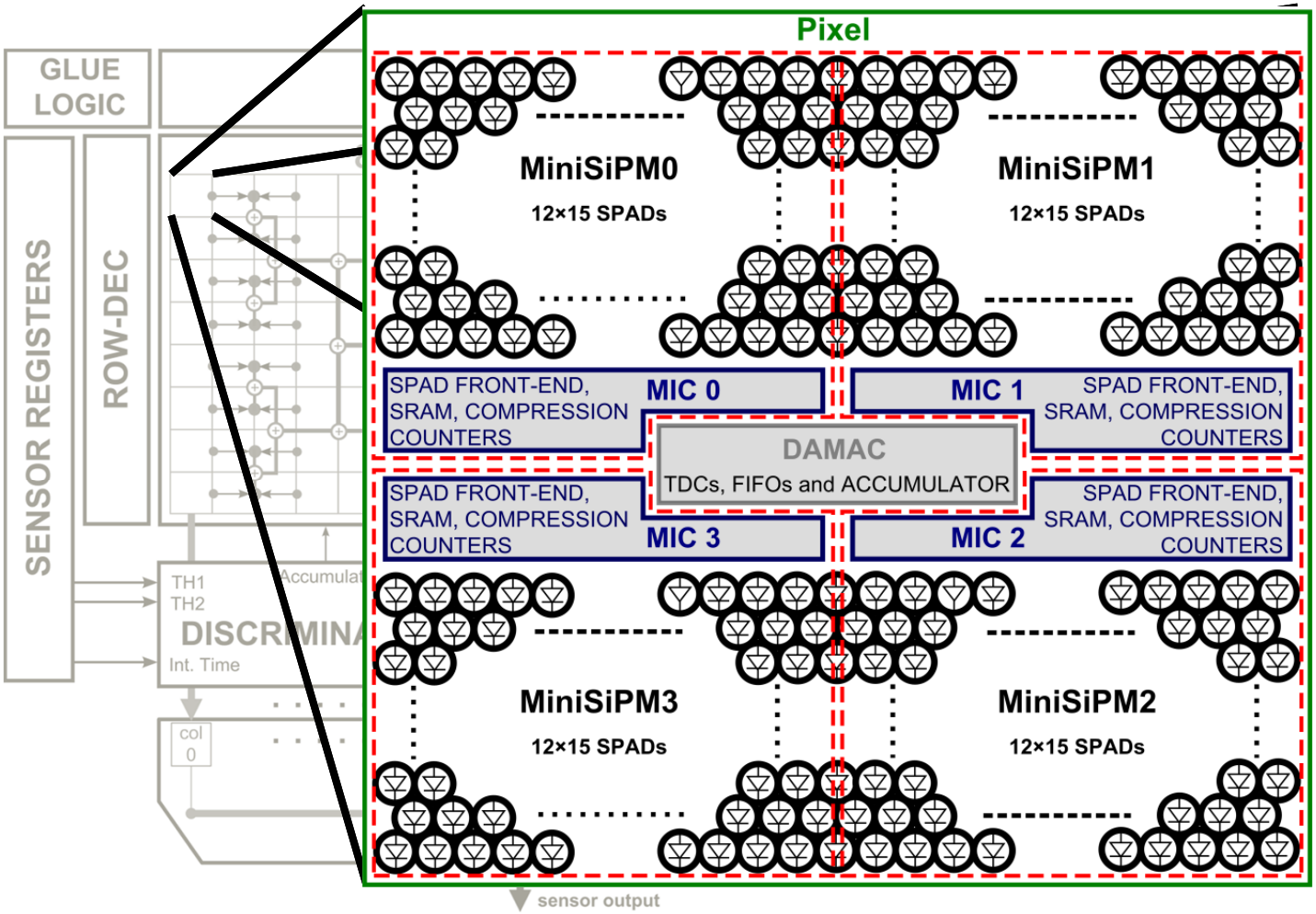
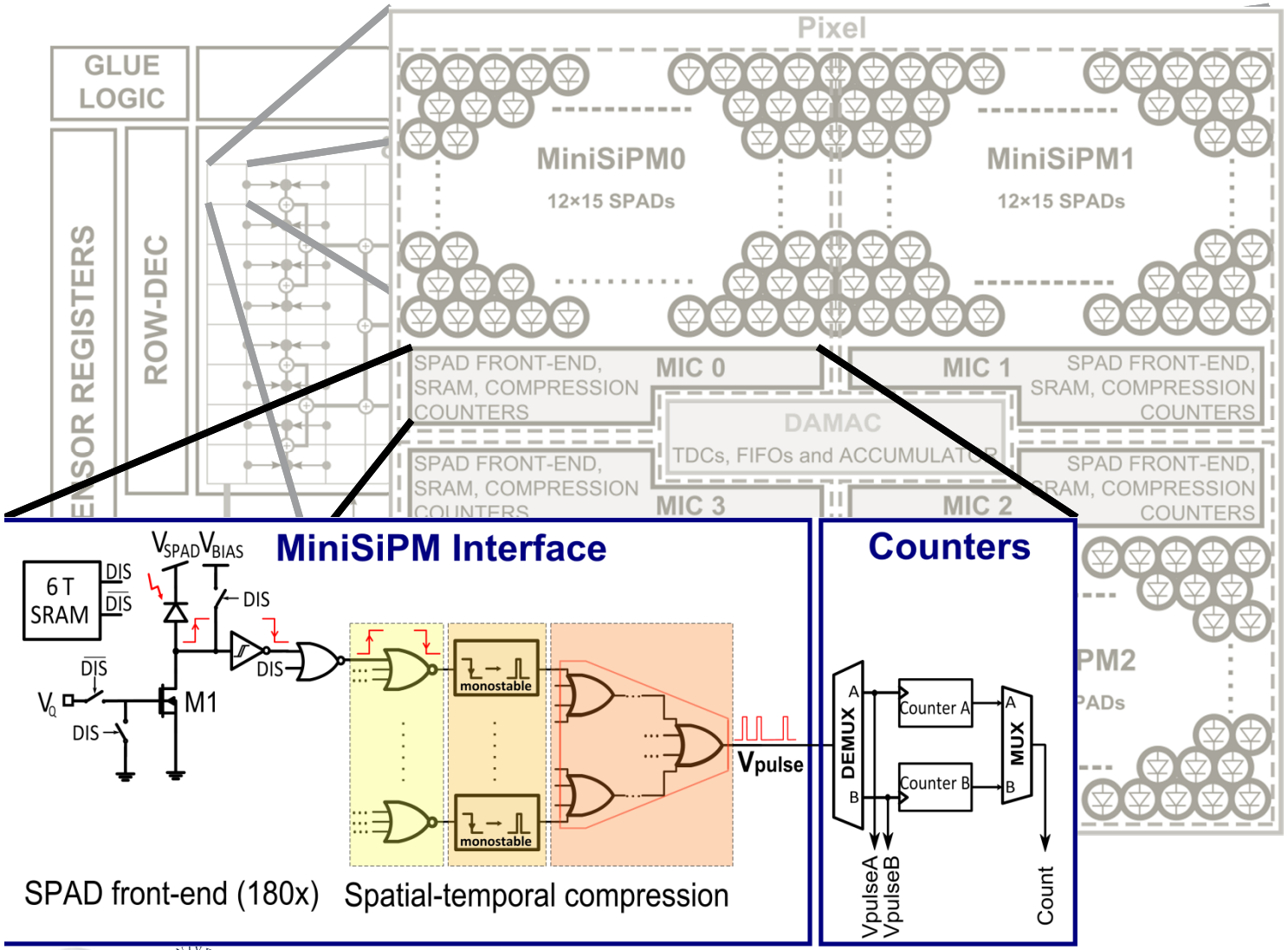


Sensor Architecture



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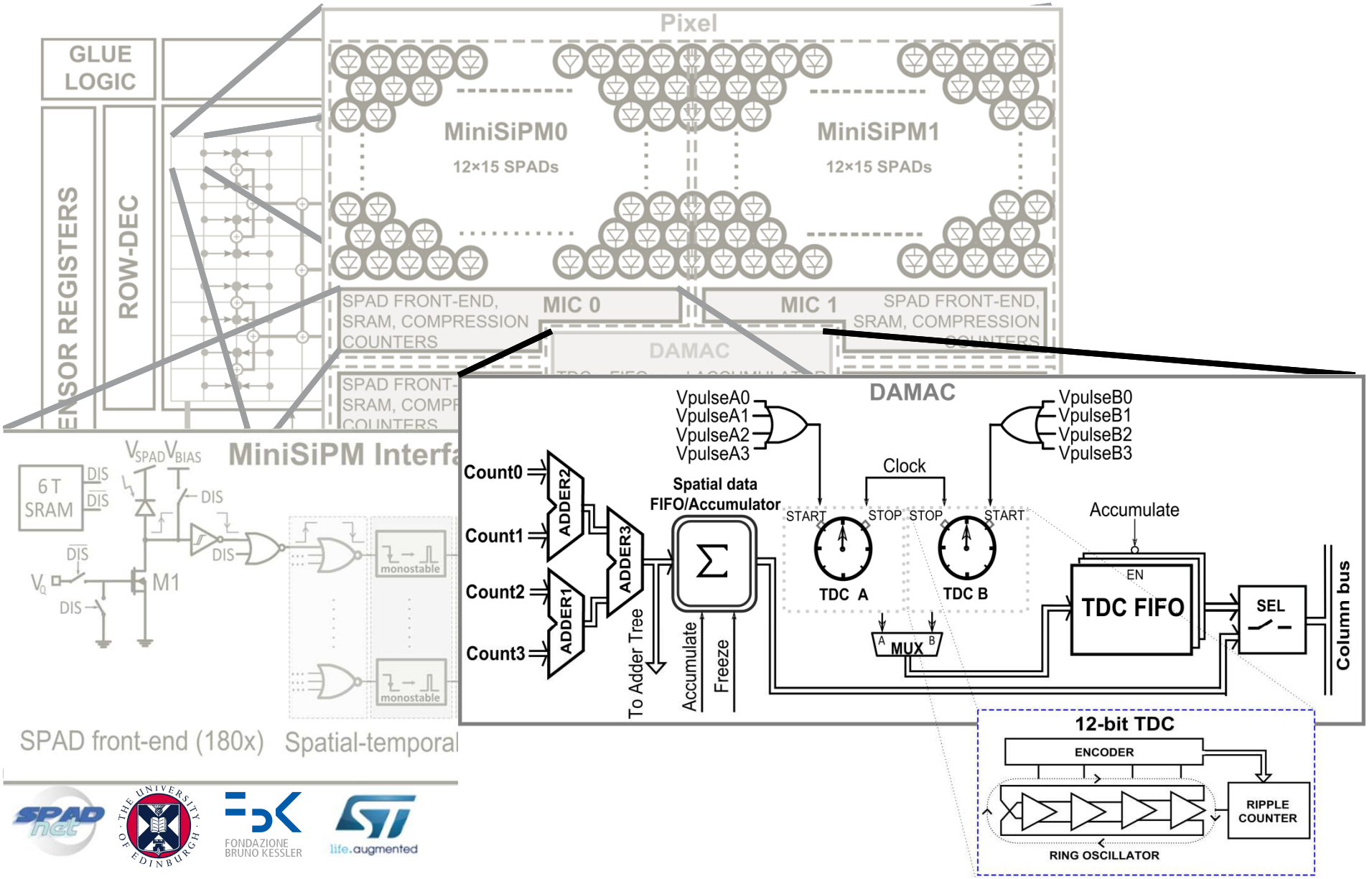
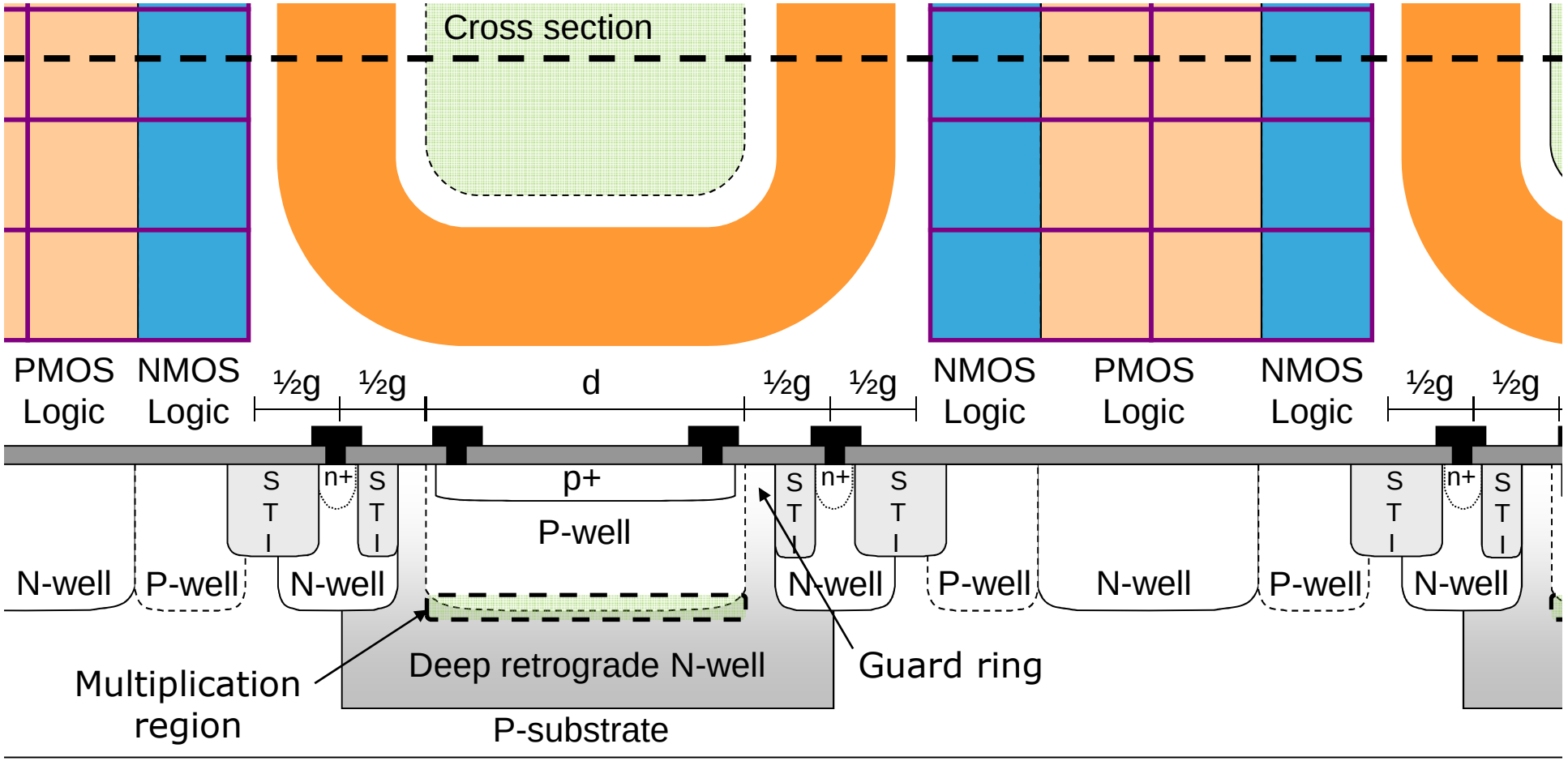
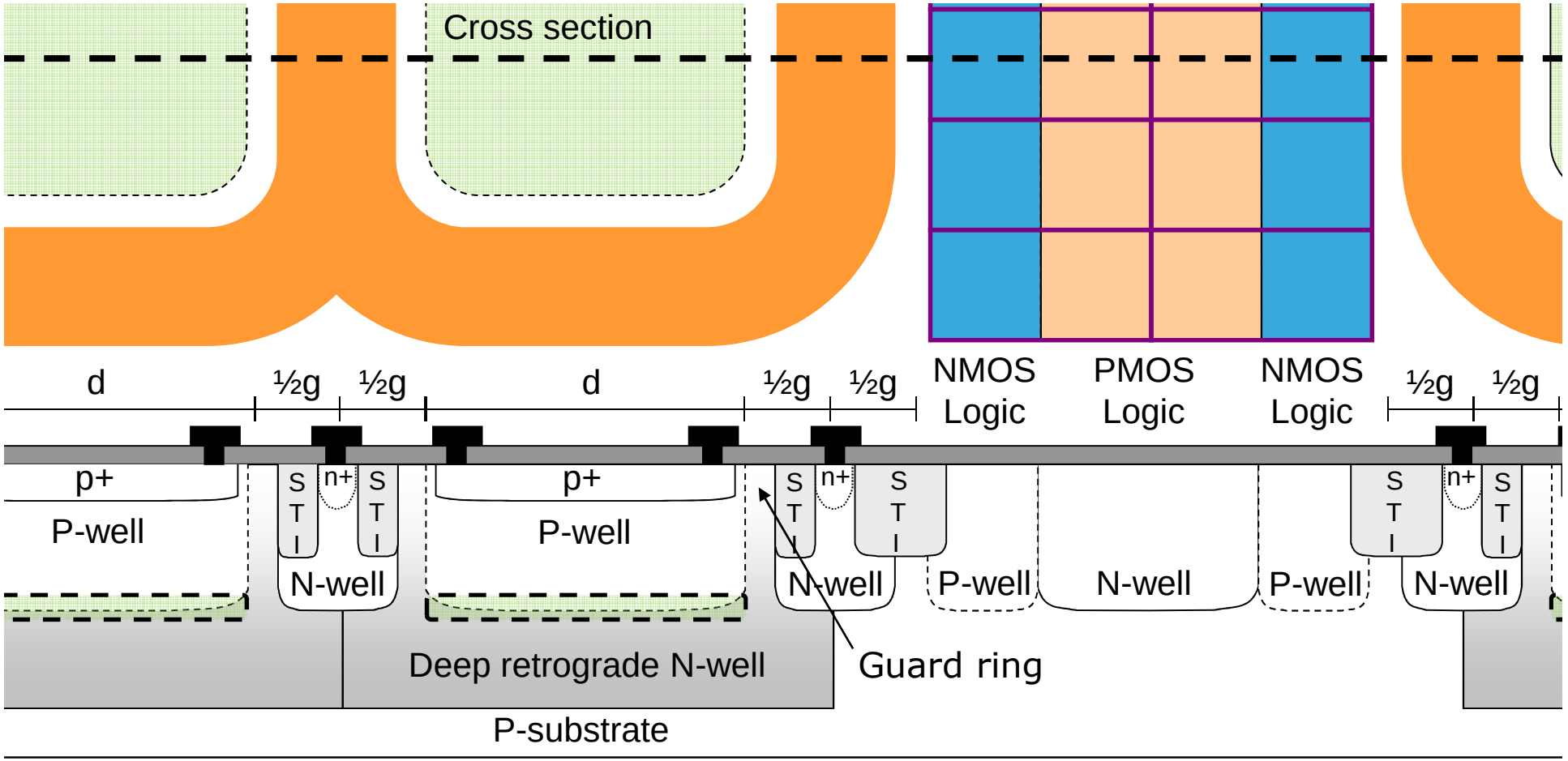


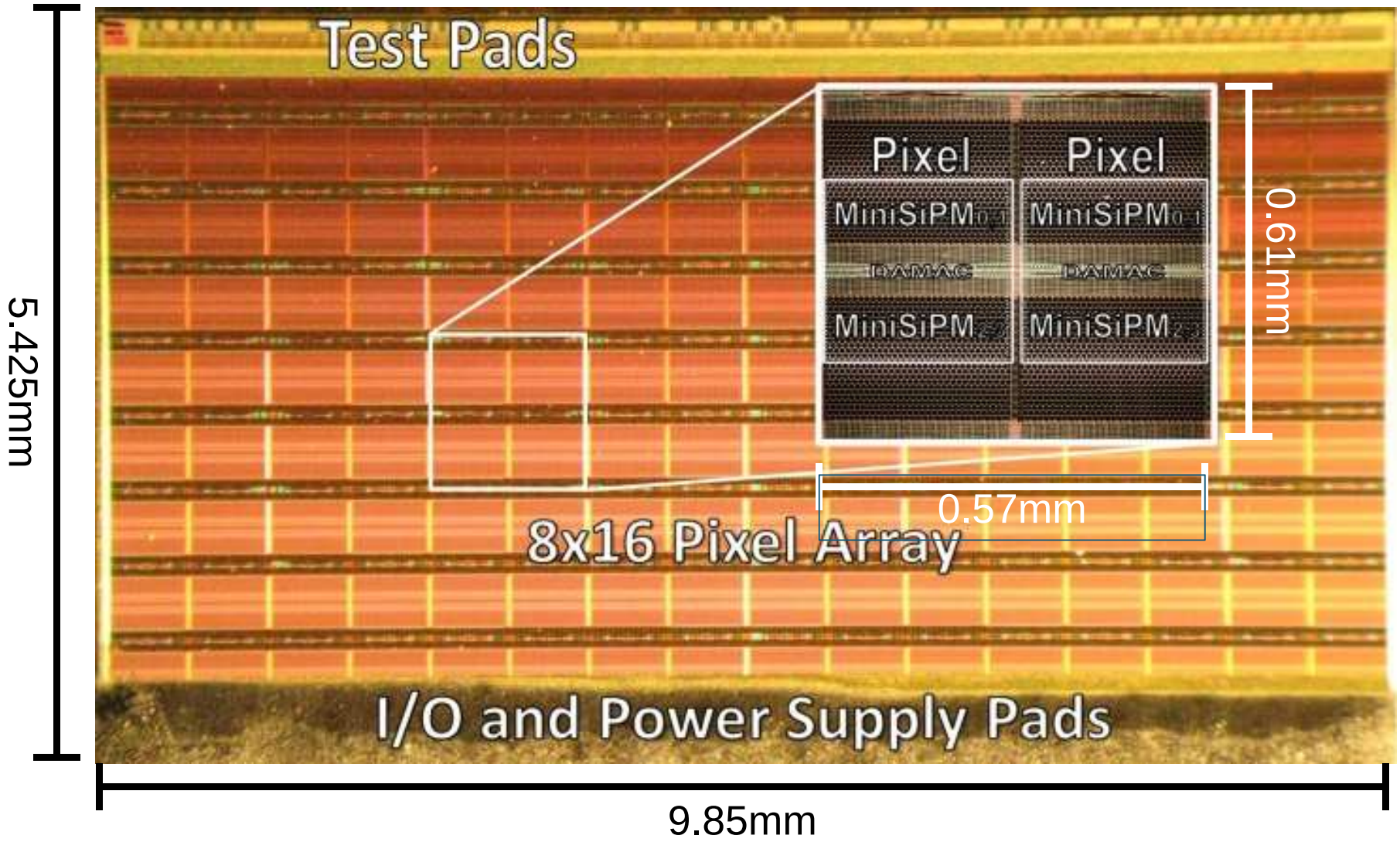
Logic per SPAD (Restricted Fill Factor)



SiPM Arrays (Fill Factor Improved)

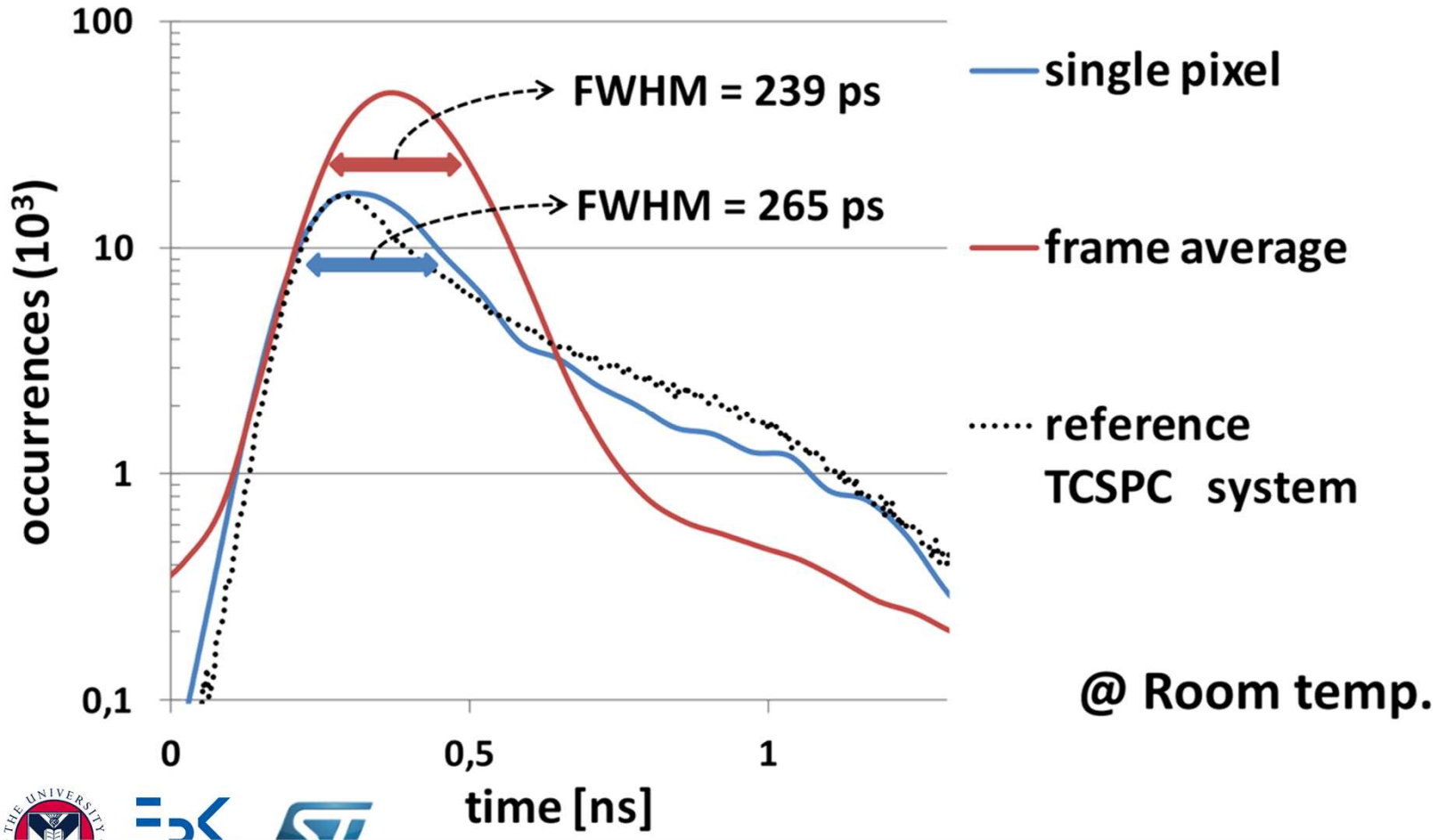


Implemented Device



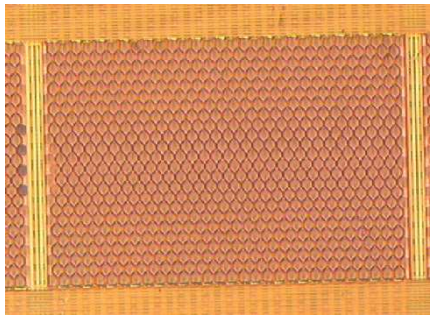
Characterisation Overview

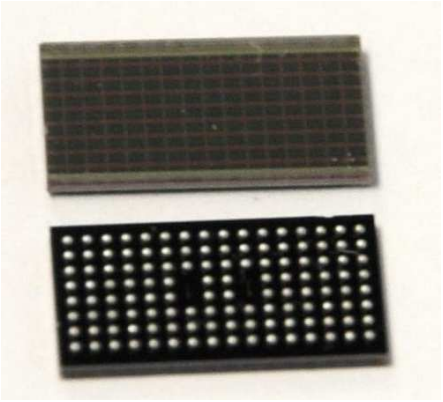
- Multiple TDCs improve system timing resolution



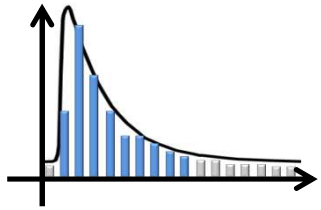
Summary

- 92k SPAD PET image sensor in 0.13µm CIS technology:
  - 8×16 pixel array
  - 0.57×0.61mm pixel
  - 43% array fill factor





- TDCs per pixel for improved timing resolution
- 100MHz real-time energy histogram output for event recognition



- On-chip discriminator for improved efficiency.

Thank you for your attention

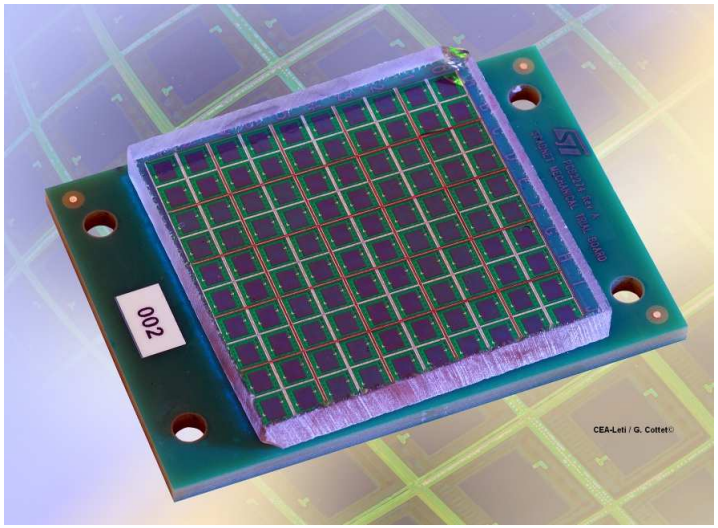
Acknowledgements:

Sensor design

Module assembly

Industrial partners

www.SPADnet.eu



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