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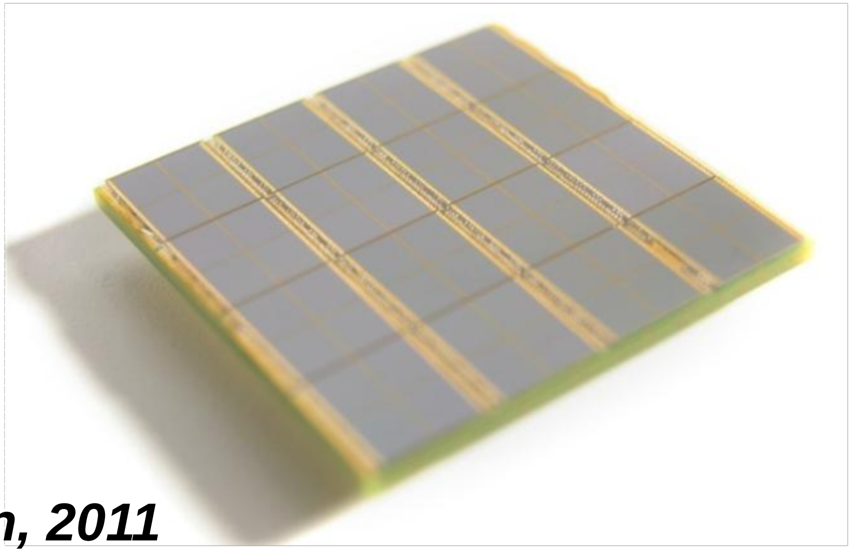
sense and simplicity

Photon Counting with arrays of Digital SiPM's



Philips Digital Photon Counting (PDPC)
Dr. York Hämisch
Anja Schmitz

SiPM event, CERN, February 17th, 2011

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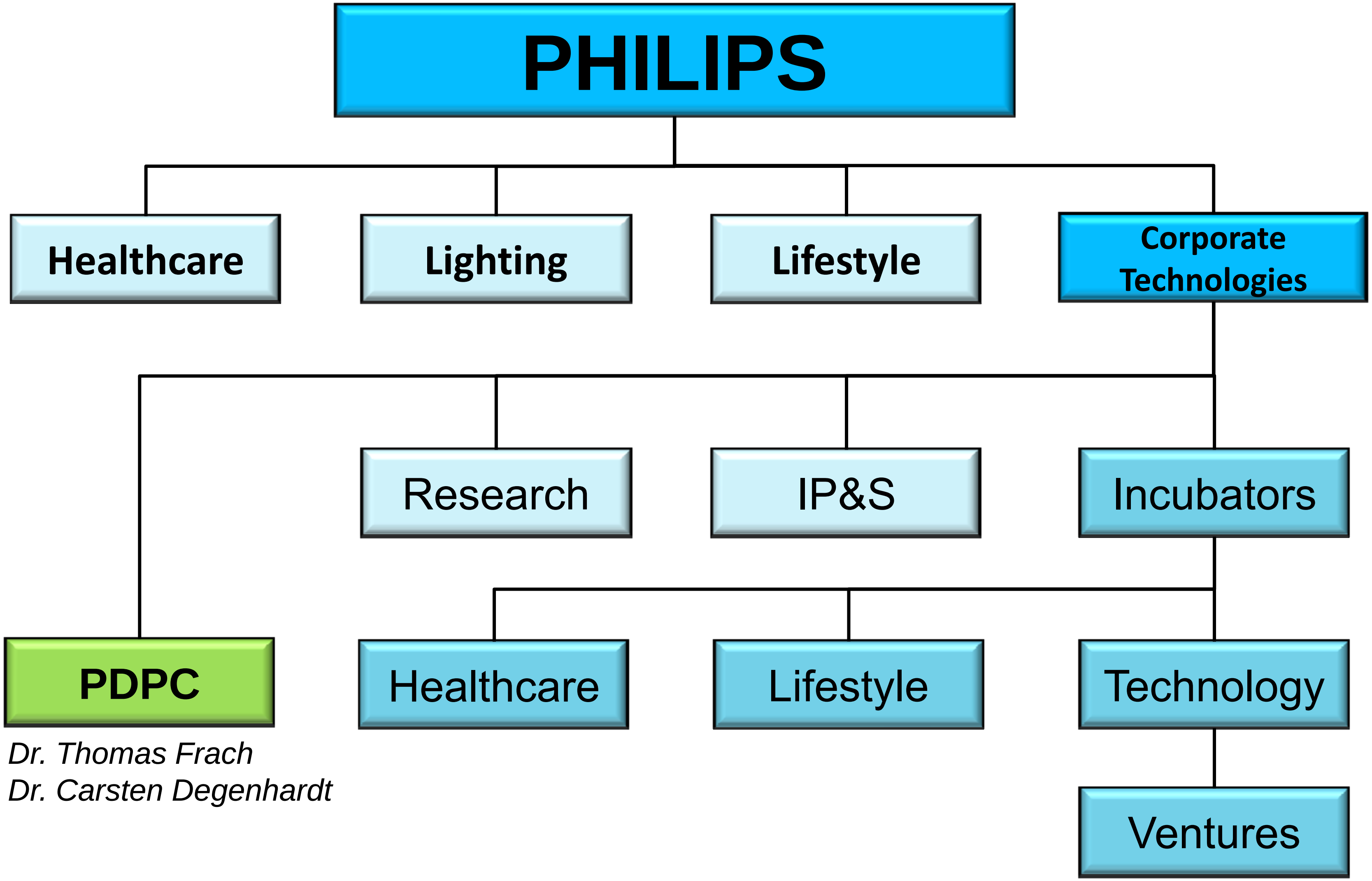
PDPC in Philips



Dr. Thomas Frach
Dr. Carsten Degenhardt

Digital Silicon Photomultipliers (dSiPM) -
The next solid state innovation

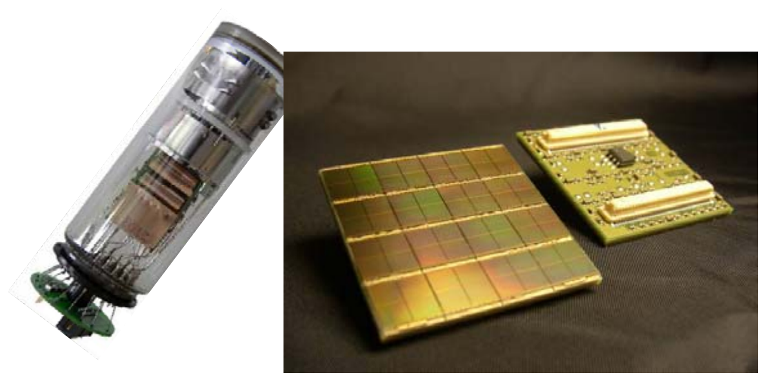
Transistor

Television

Digital Camera

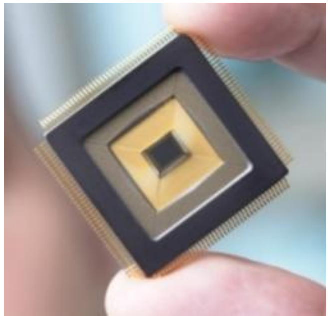
X-Ray imaging

Digital Photon Counting

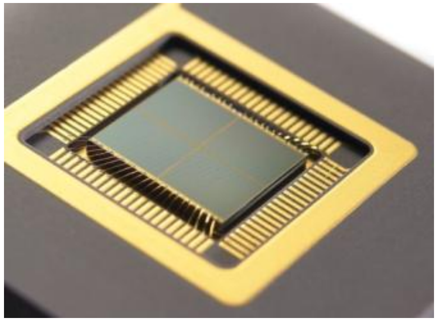


How to replace old-fashioned PMT's?

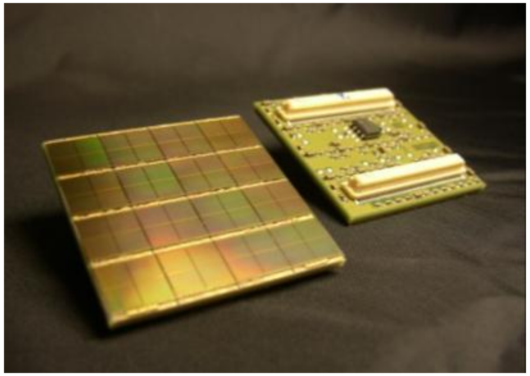
- Make the SiPM digital
  - 1 pixel



- Increase integration
  - 2 x 2 pixel on one chip (die)



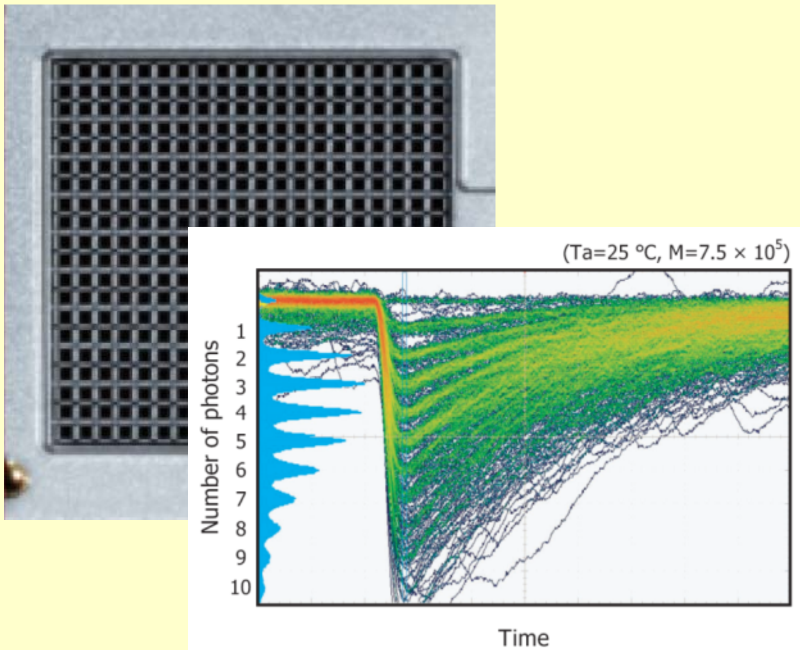
- Assemble arrays
  - 8 x 8 pixels on one PCB (tile)



Digital Photon Counting – The concept

Intrinsically, the SiPM is a digital device: a single cell breaks down or not

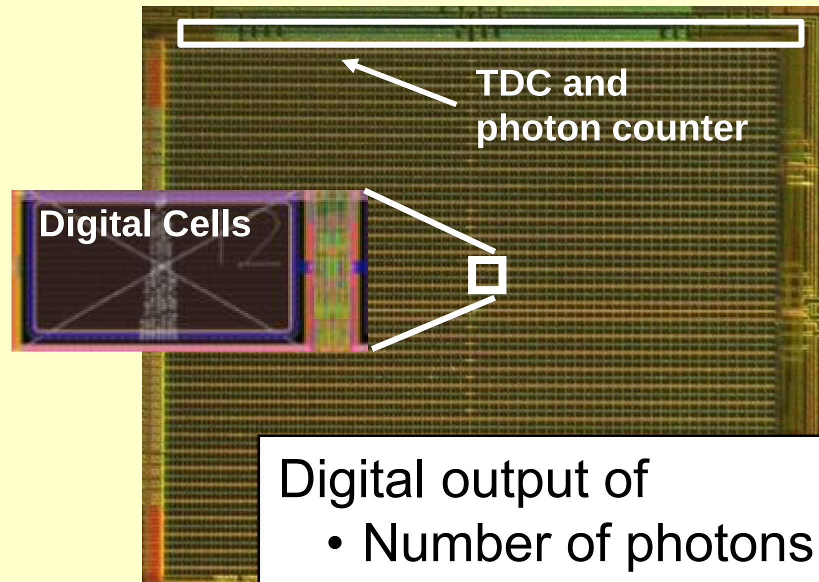
analog SiPM



www.hamamatsu.com

Summing all cell outputs leads to an analog output signal and limited performance

digital SiPM (dSiPM)

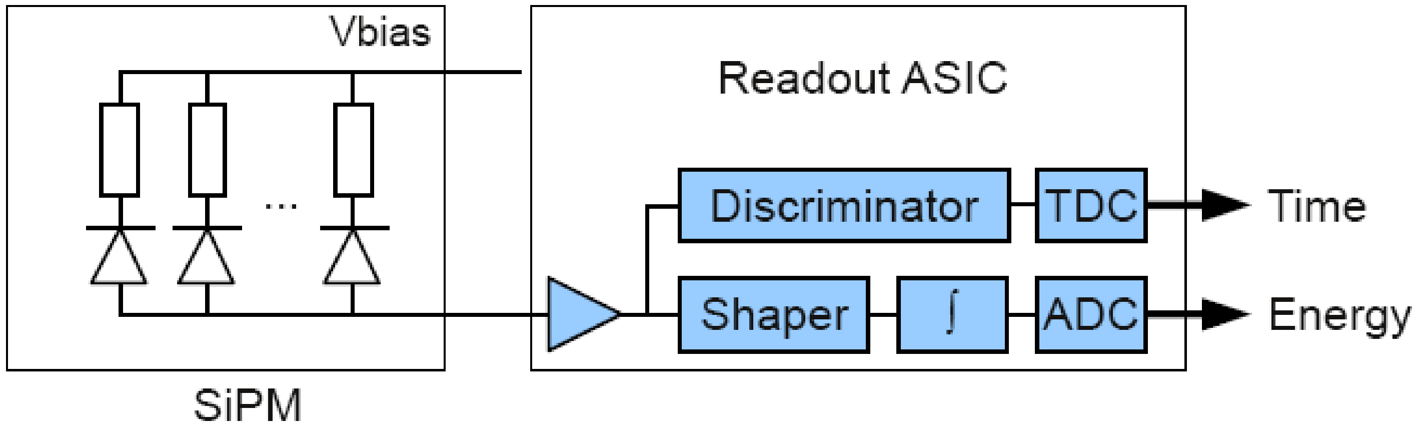


Digital output of
- Number of photons
- Time-stamp

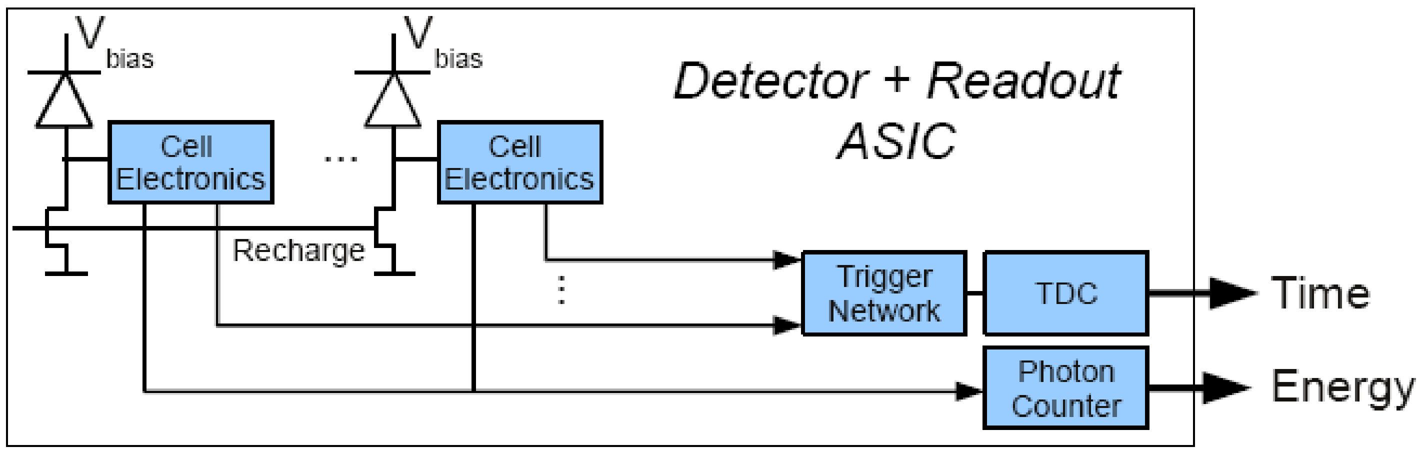
Integrated readout electronics is the key element to superior detector performance

Analog vs. Digital SiPM

Analog Silicon Photomultiplier Detector



Digital Silicon Photomultiplier Detector



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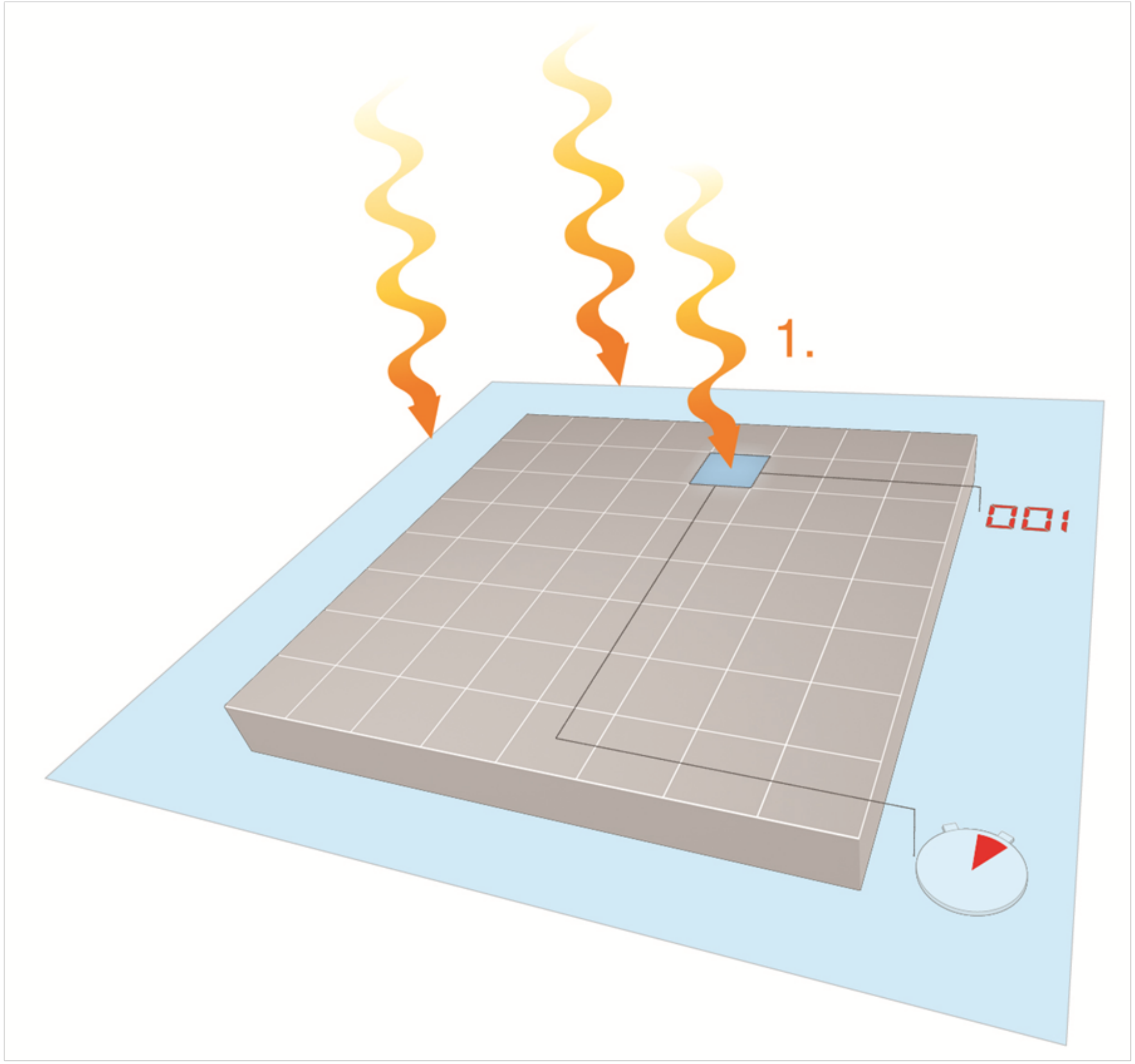
Digital SiPM: Principle



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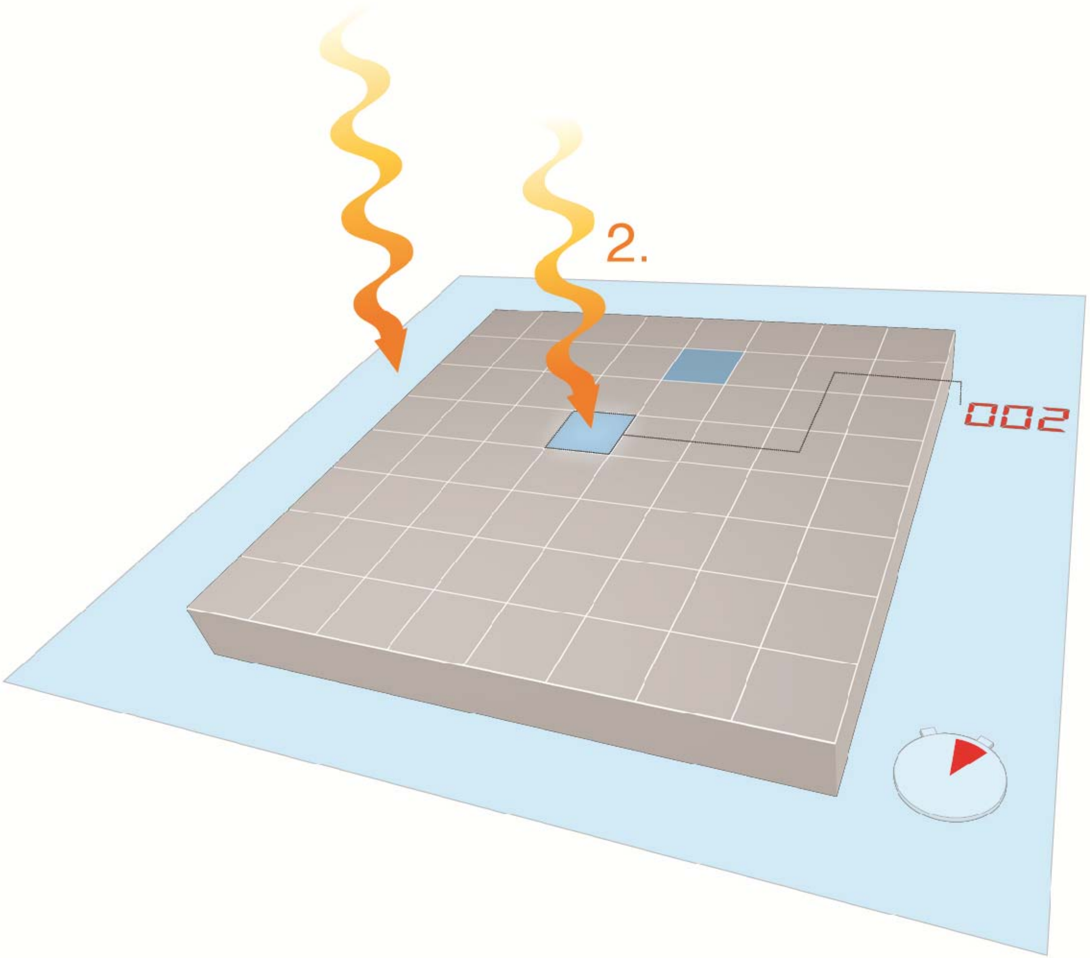
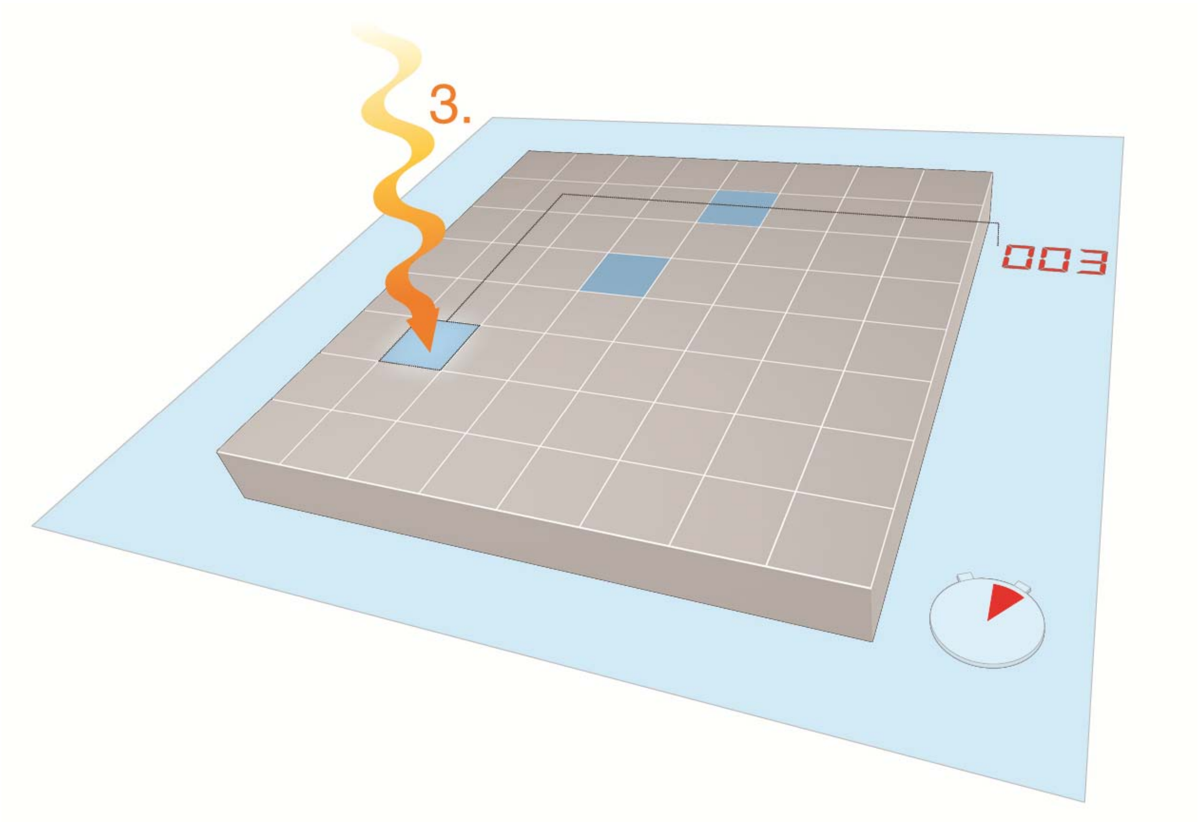
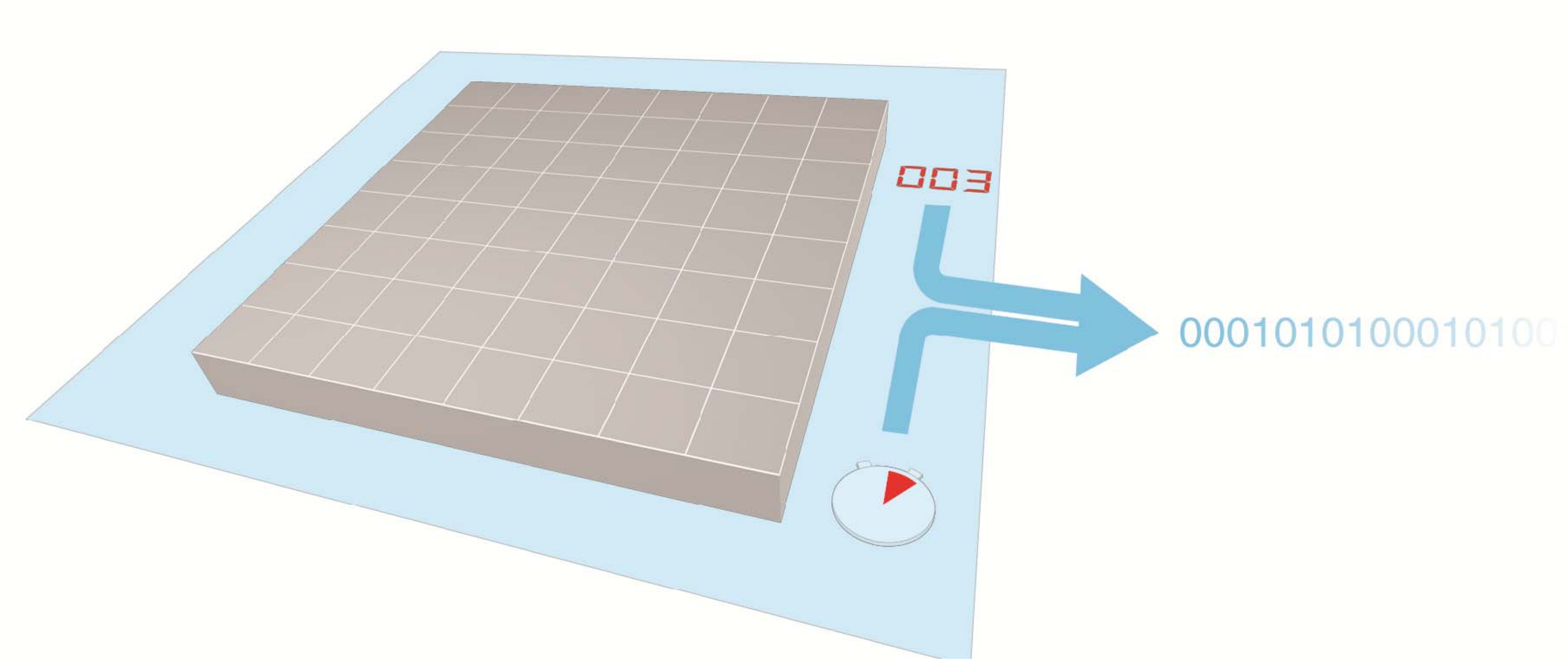
Digital SiPM: Principle



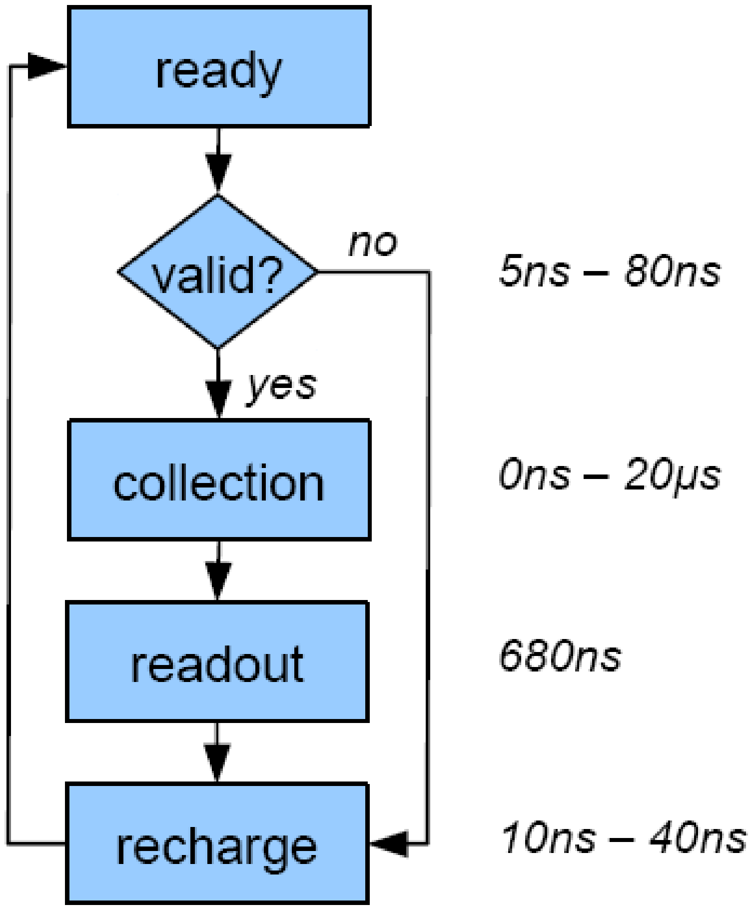
Digital SiPM: Principle



Digital SiPM: Principle



Digital SiPM: Acquisition sequence
(example)



- *200MHz (5ns) system clock*
- *Variable light collection time up to 20µs*
- *20ns min. dark count recovery*
- *dark counts => sensor dead-time*
- *data output parallel to the acquisition of the next event (no dead time)*
- *Trigger at 1, ≥2, ≥3 and ≥4 photons*
- *Validate at ≥4 ... ≥64 photons (possible to bypass event validation completely)*

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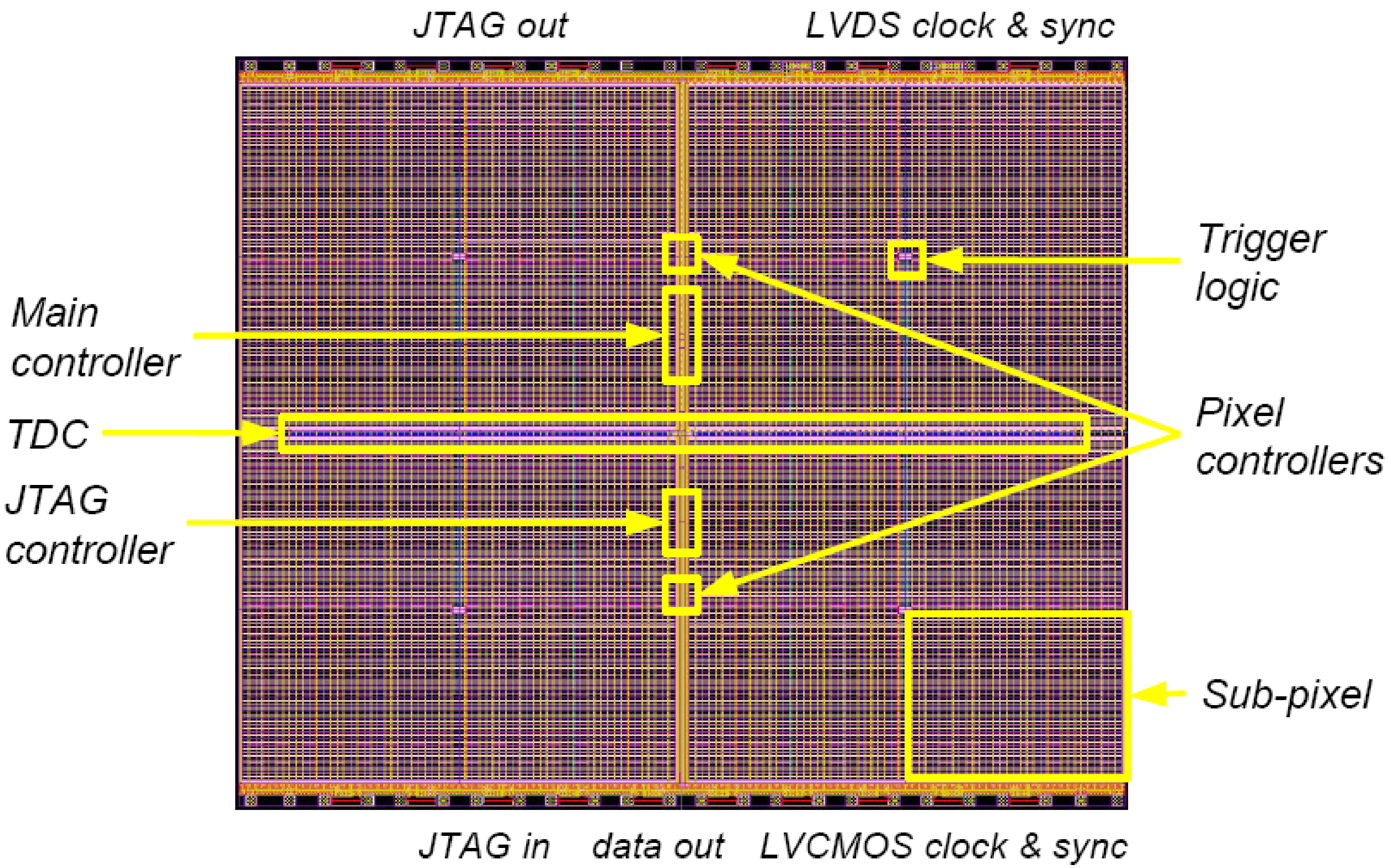
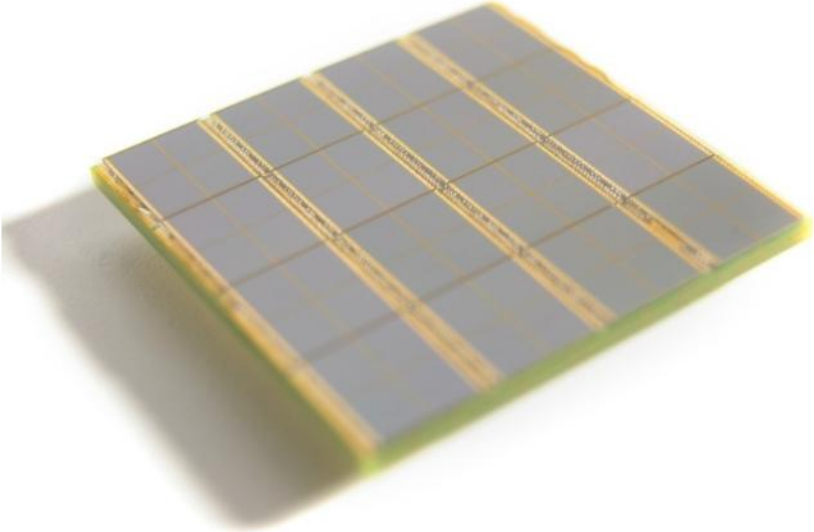
PDPC Digital SiPM: architecture (die)



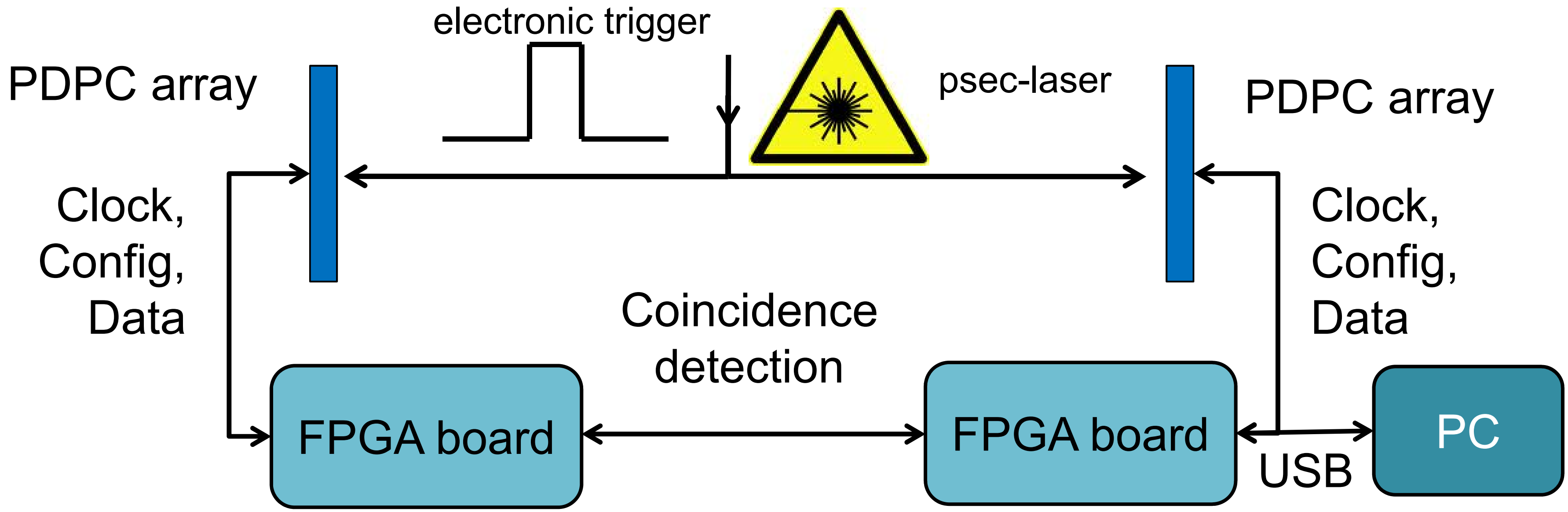
Digital SiPM array (tile)

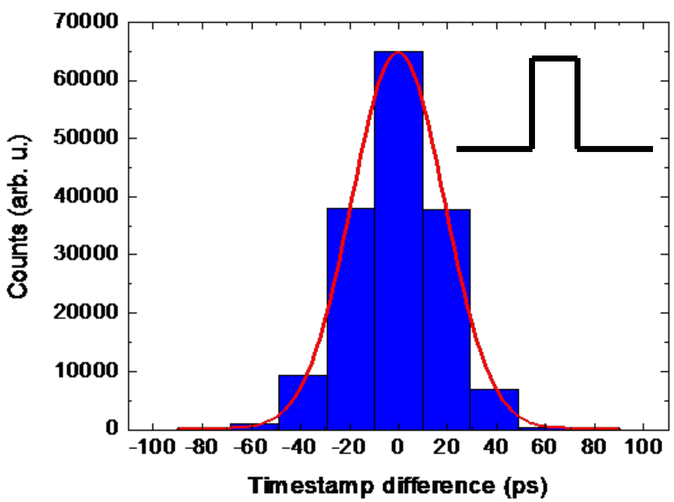
Features

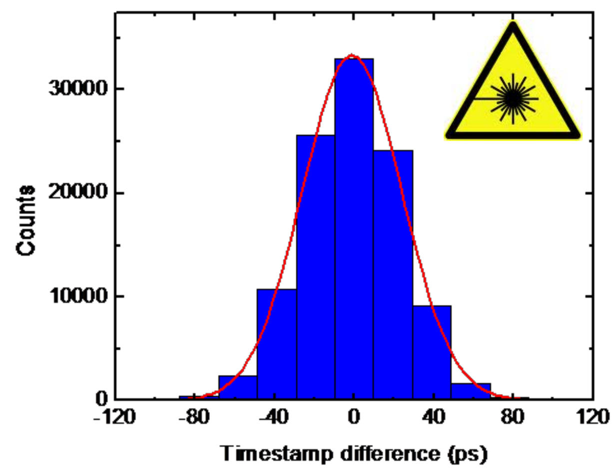
- 8 x 8 digital SiPMs (on 4 x 4 chips)
- 6400 diodes (cells) per pixel
- ~ 11 cm^2
- 4-side tiling possible
- Inputs
  - 1.8 V, 3.3 V, 30 V
  - JTAG (test and configuration)
  - 200 MHz reference clock
  - External trigger input
- Outputs
  - 100 MHz serial data (photon count, timestamp)
  - Event detect trigger



PDPC dSiPM: intrinsic timing resolution







Timing jitter: **44 ps FWHM** **59 ps FWHM**

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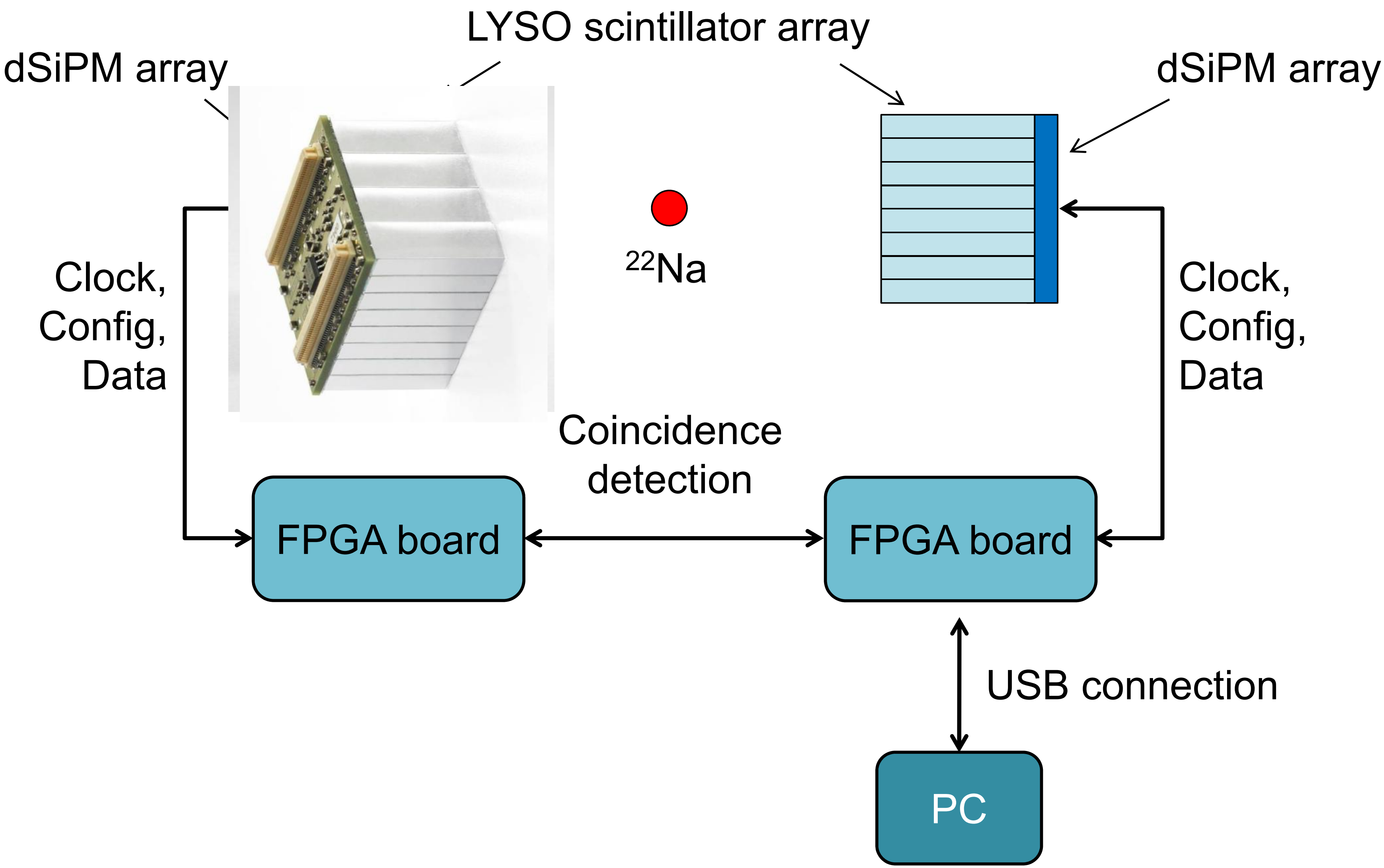
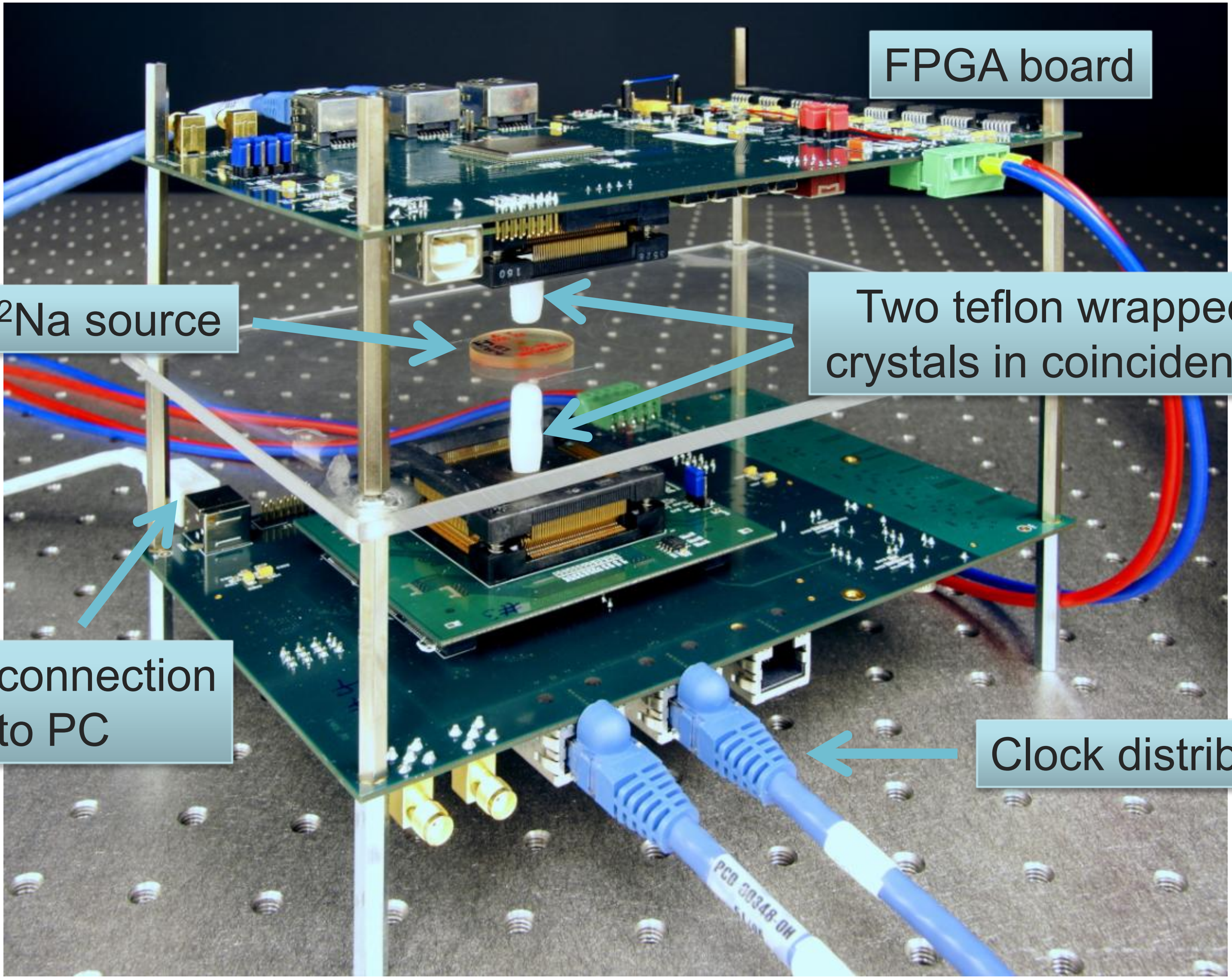
PDPC scintillator coincidence setup

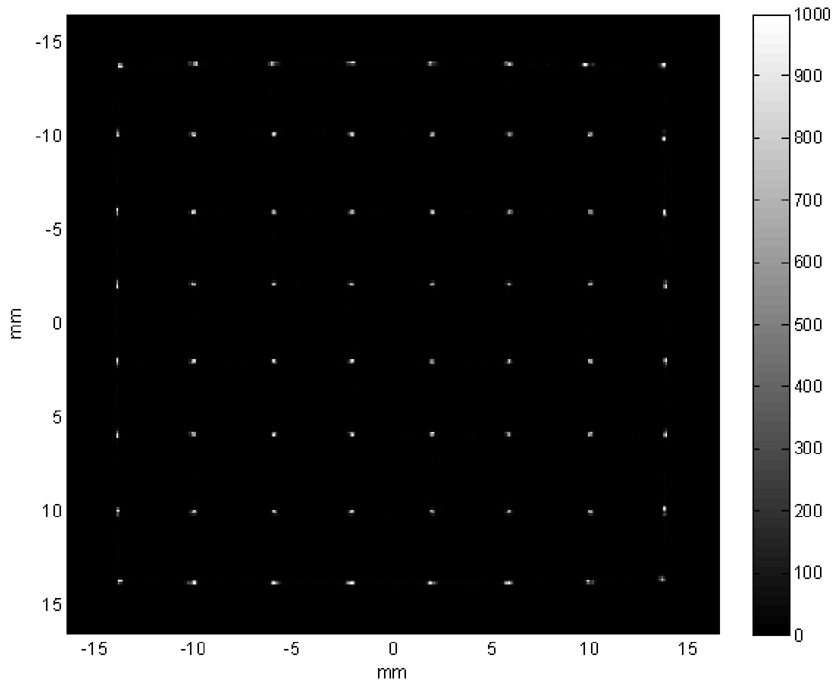


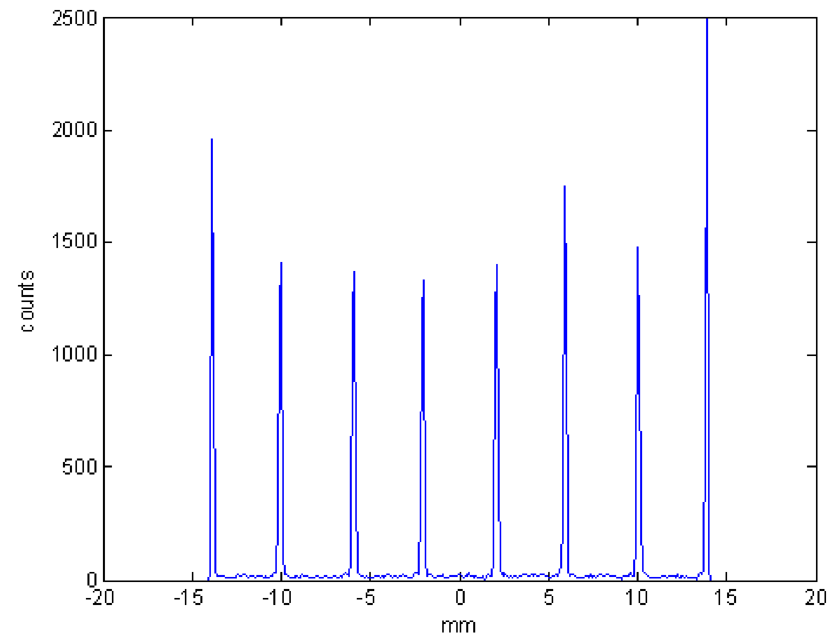
PDPC test setup (available Q2-11)



PDPC dSiPM: Scintillator readout (1:1 coupling)
Floodmap

- LYSO array, 8 x 8 crystals, 4 mm x 4 mm pitch, 22 mm length





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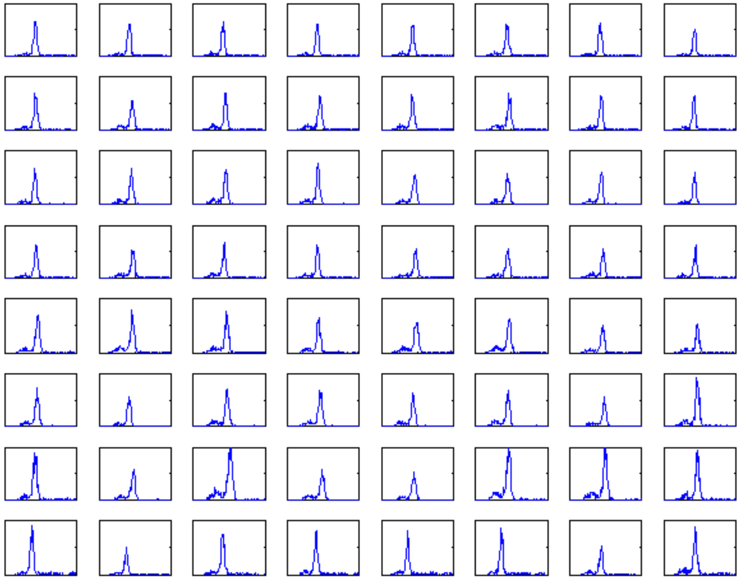
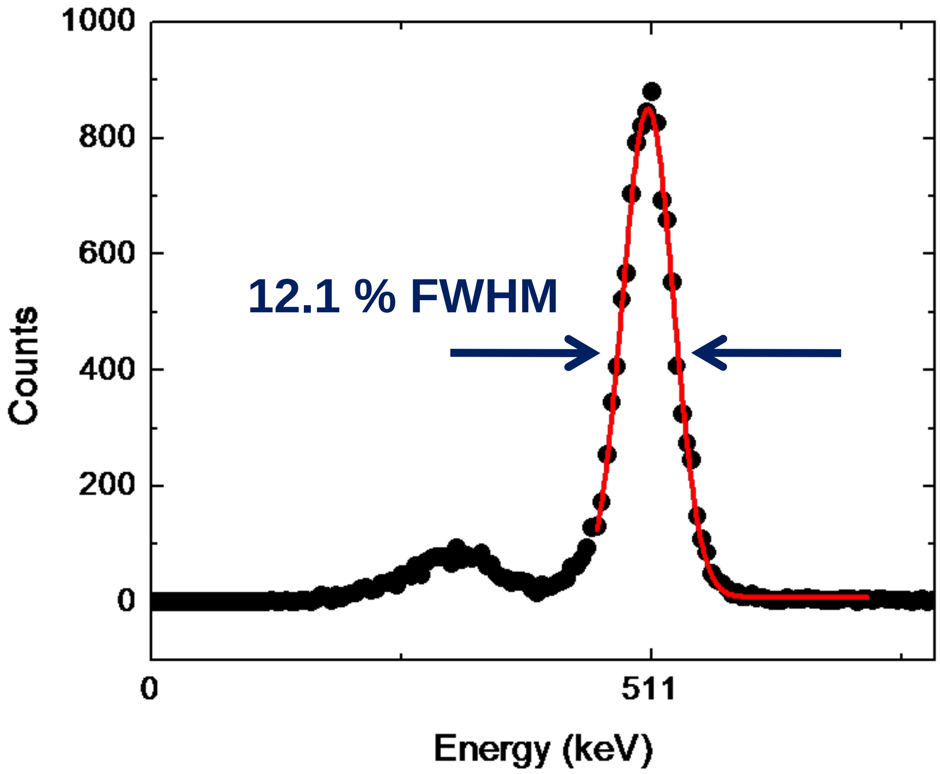
PDPC Digital SiPM

Energy resolution





- LYSO array, 8 x 8 crystals, 4 mm x 4 mm pitch, 22 mm length
- Saturation was corrected for

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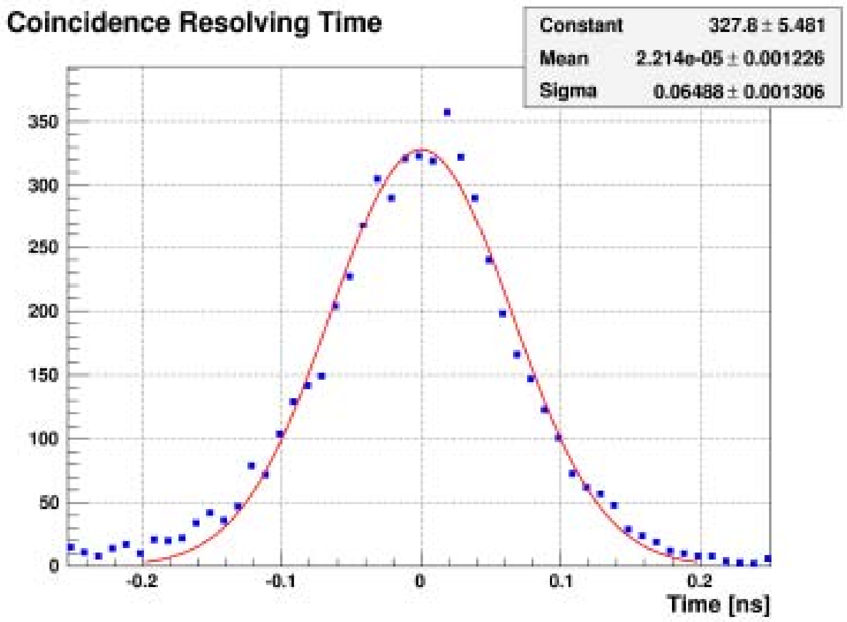
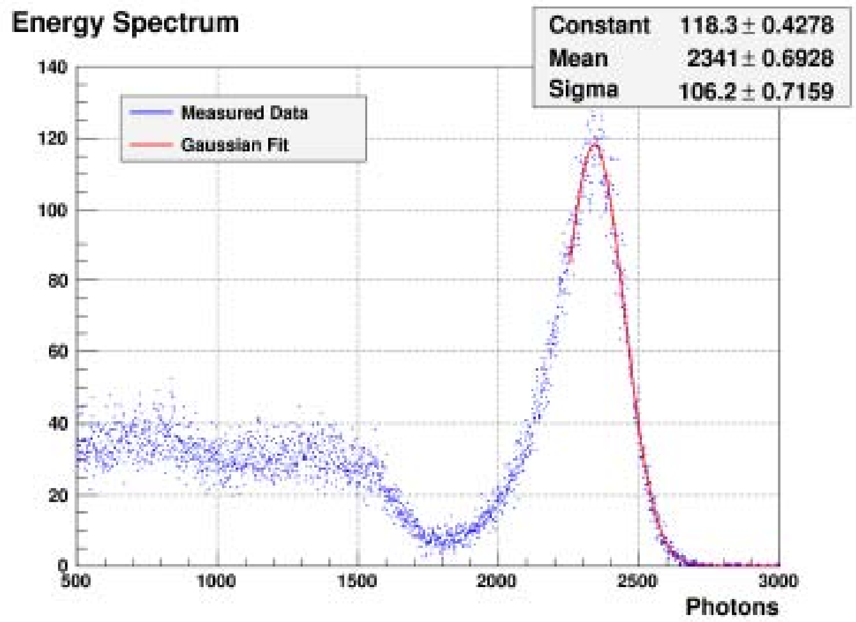
PDPC dSiPM: Coincidence timing resolution

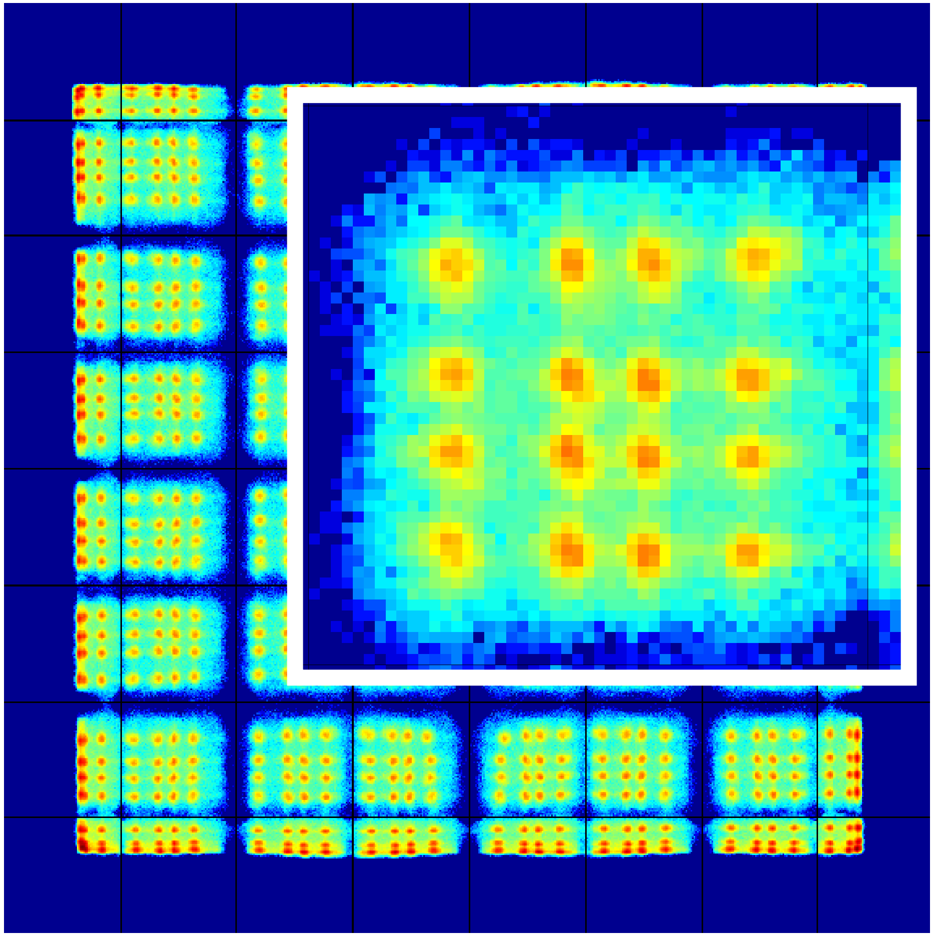




- 3X3x5 mm³ LYSO in coincidence, ^{22}Na source
- Time resolution in coincidence: **153ps** FWHM
- Energy resolution (excluding escape peak): **10.7**%
- Excess voltage 3.3V, 98.5% active cells
- Room temperature (31°C board temperature, not stabilized)

PDPC dSiPM: Small crystal readout

LYSO array, 30 x 30 crystals, 1 mm x 1 mm pitch, 10 mm length



Log scale

Data analysis by P. Düppenbecker, Philips Research

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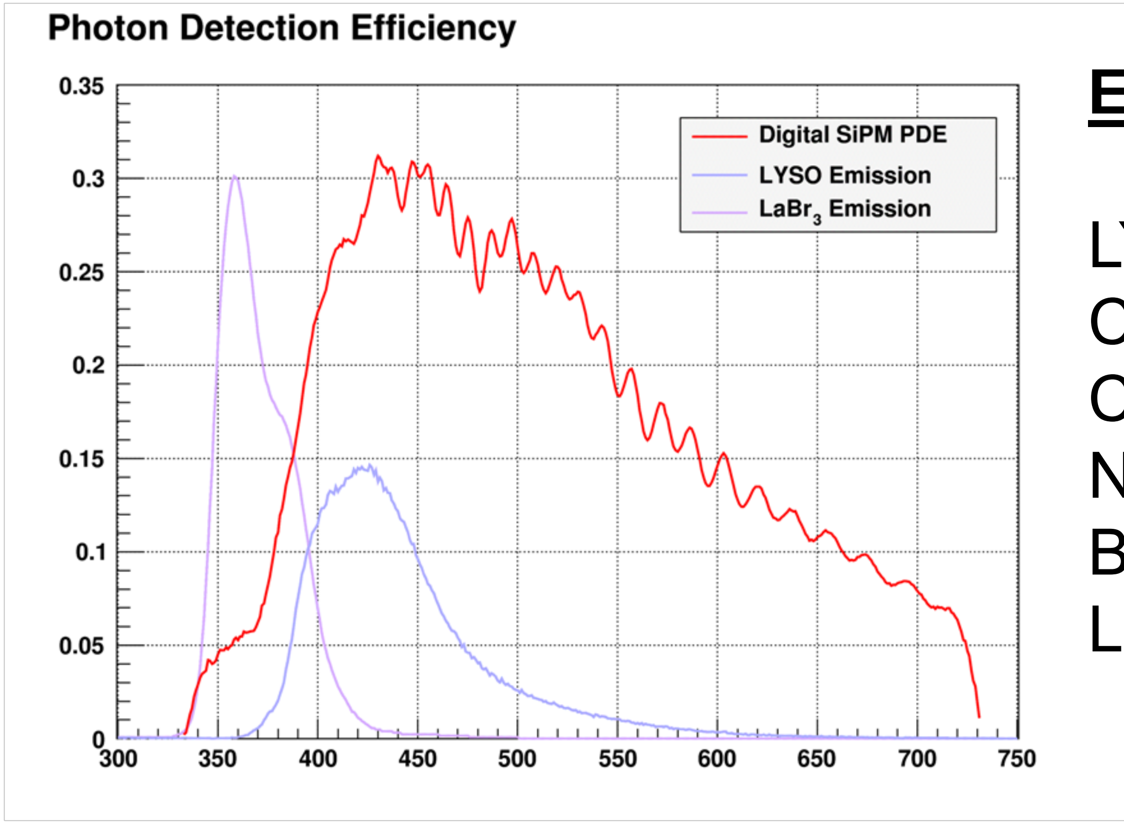
PDPC dSiPM: Spectral sensitivity



Effective PDE:

LYSO(Ce)	25.9%
CsI(Na)	23.7%
CsI(Tl)	20.5%
NaI(Tl)	24.2%
BGO	24.2%
$LaBr_3$(Ce)	9.6%

- Peak PDE ~30% at 430nm and 3.3V excess voltage
- Conservative diode design (50 % fill-factor)
- No anti reflection coating used

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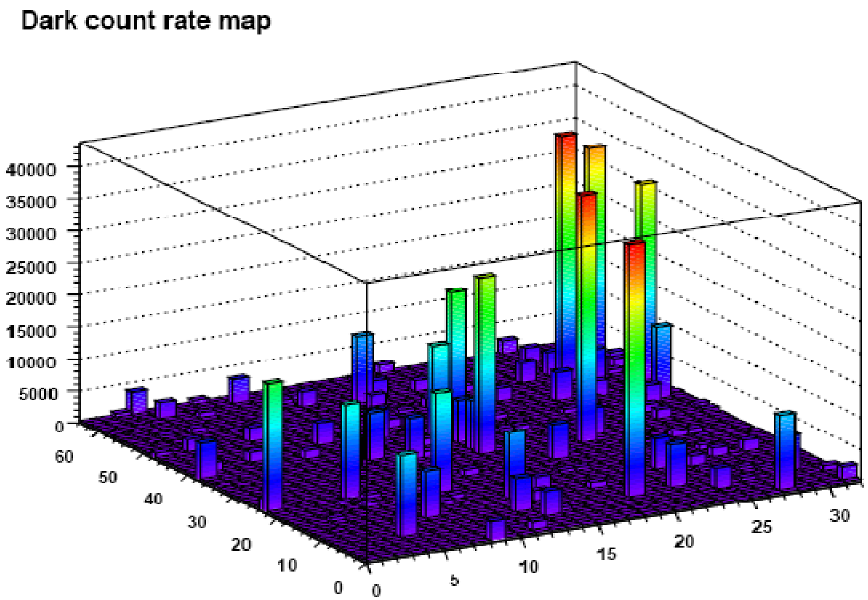
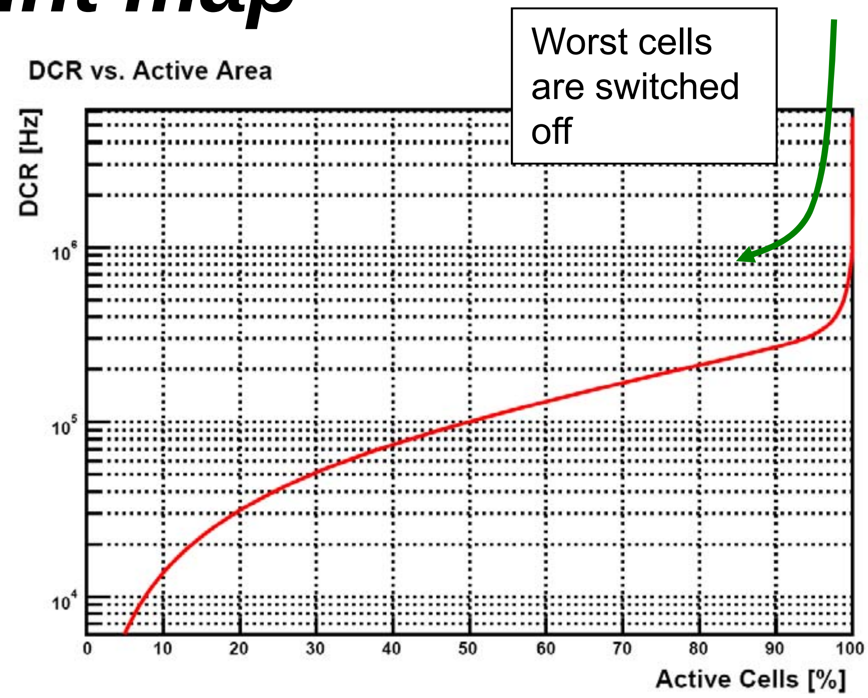
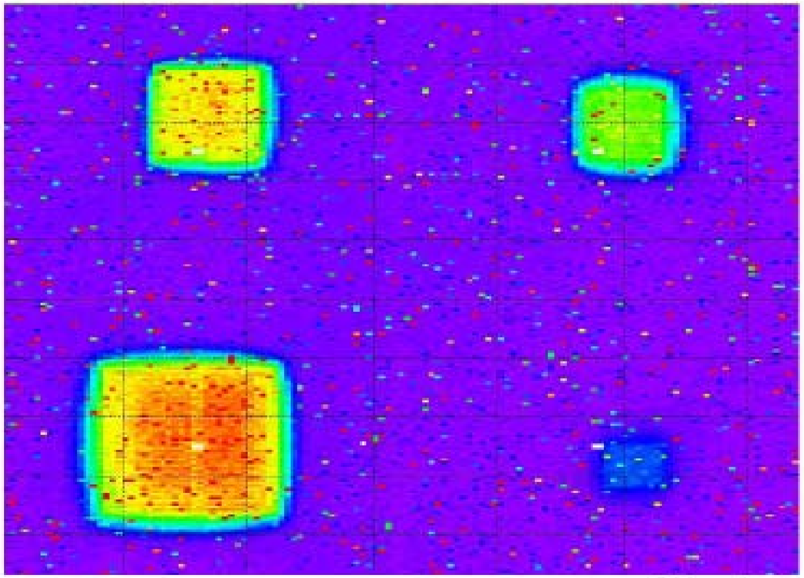
PDPC dSiPM: Dark count map



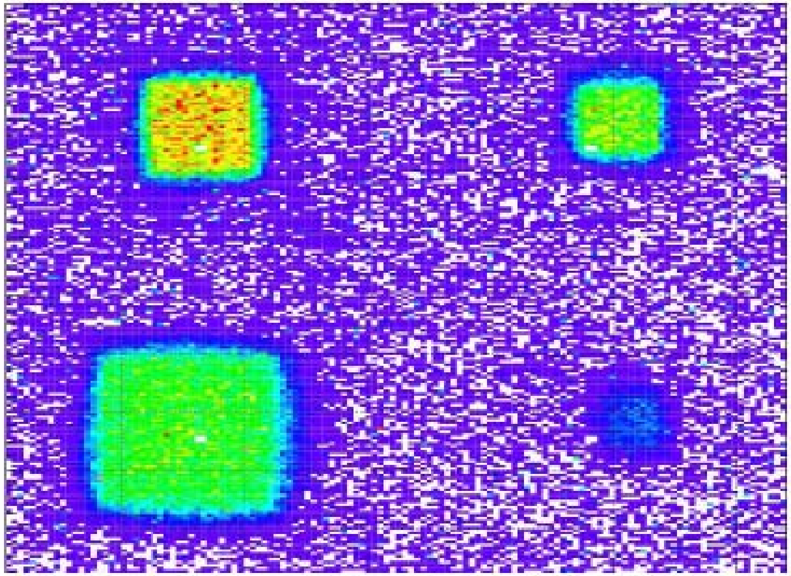


- Dark counts per second at 20°C and 3.3V excess voltage
- ~ 95% good diodes (dark count rate close to average)
- Typical dark count rate at 20°C and 3.3V excess voltage: ~150Hz / diode
- Dark count rate drops to ~1-2Hz per diode at -40°C

PDPC dSiPM: slow scan imaging mode

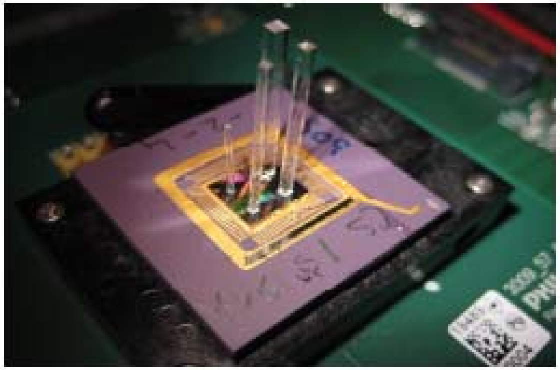


Singles

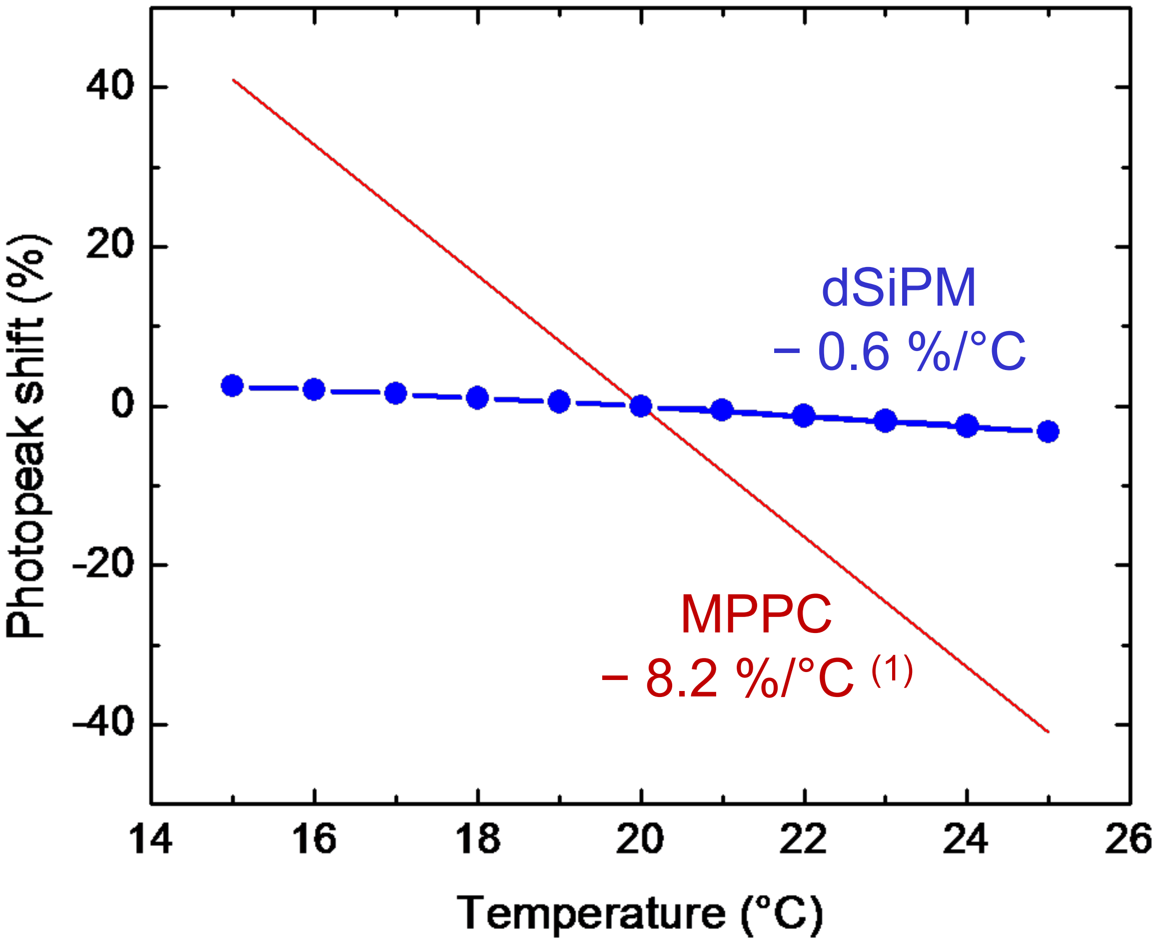


Coincidences

- *Spatial sampling of the light distribution*
- *Similar to dark count map measurement*
- *Dark count map can be used for correction*
- *Alternatively, use coincidence to reduce noise*
- *Potentially useful for light guide design*



PDPC dSiPM: Temperature dependence

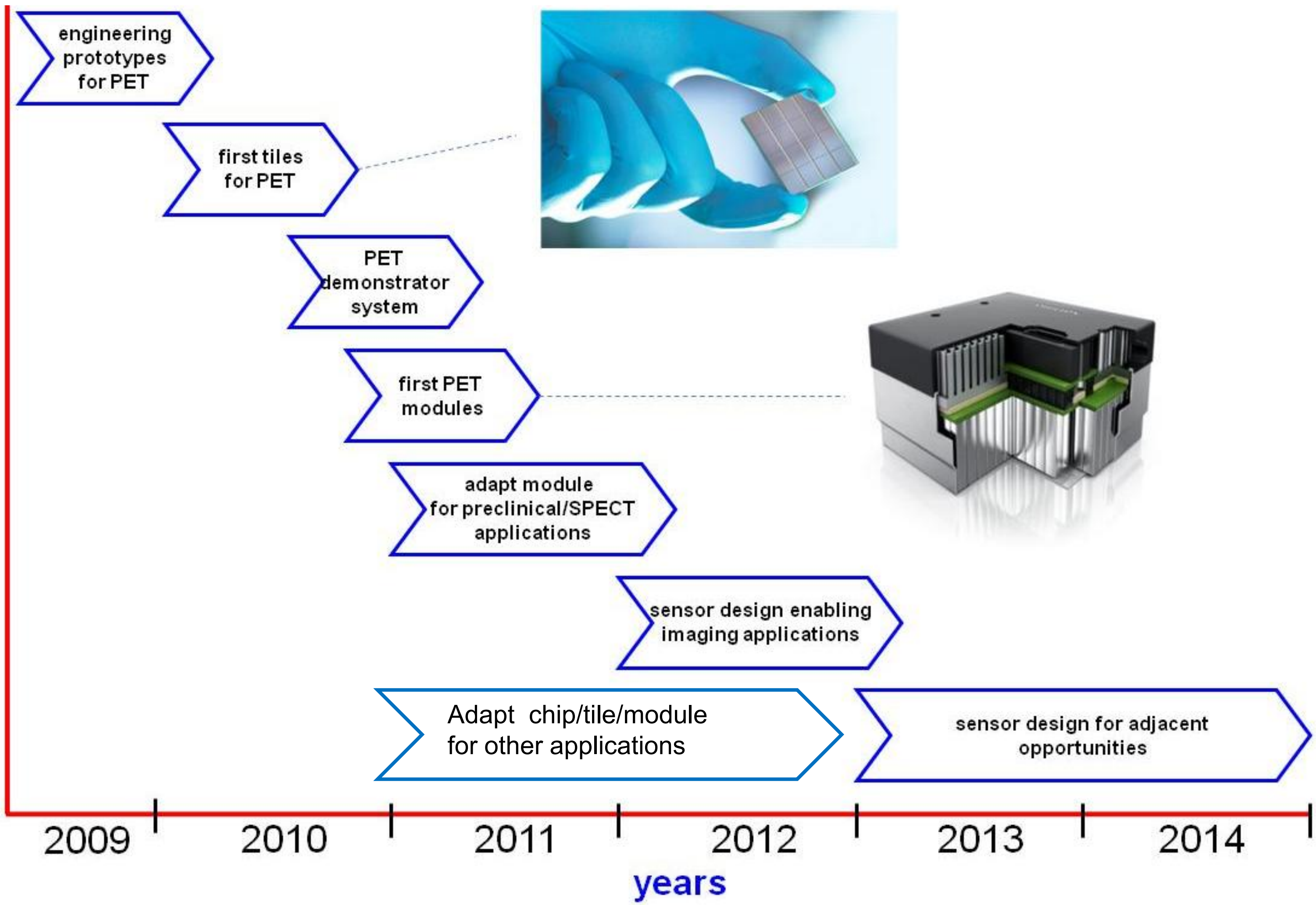


Temperature dependent light output of LYSO:

− 0.2 %/°C (2)
− 0.45 %/°C (3)

[1] K. Burr et al, Nuclear Science Symposium Conference Record, N18-2, 2007
[2] R. Mao et al, IEEE Transactions of Nuclear Science, vol. 55, 2008
[3] C. Kim, Nuclear Science Symposium Conference Record, M07-113, 2005

PDPC: Technology Roadmap



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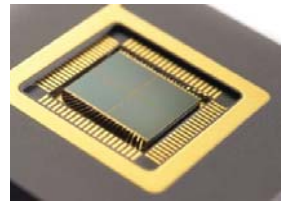
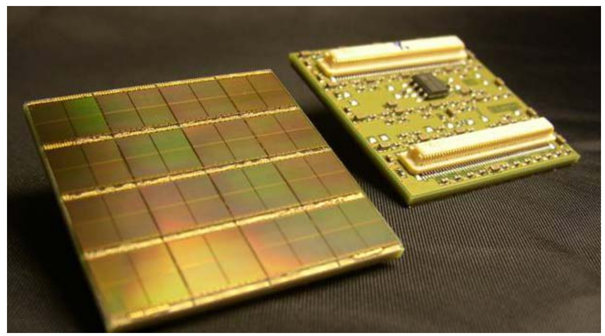
PDPC sensors: simplified electronic design

die
(2 x 2 pixel)



no. of photons/pixel

tile-PCB
(16 dies + ***FPGA****)*



time stamping
sorting, control

module PCB
(n-tiles)

tile power supply,
clustering, Anger logic

processing unit

e.g. coincidence
processing

All digital

PDPC sensors: Benefits

Application

Speed

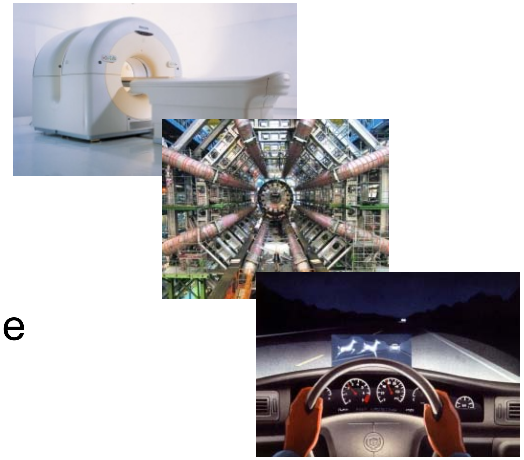
- Outstanding timing resolution (e.g. for TOF)

Sensitivity

- Lower dark count level (background noise) than analogue systems

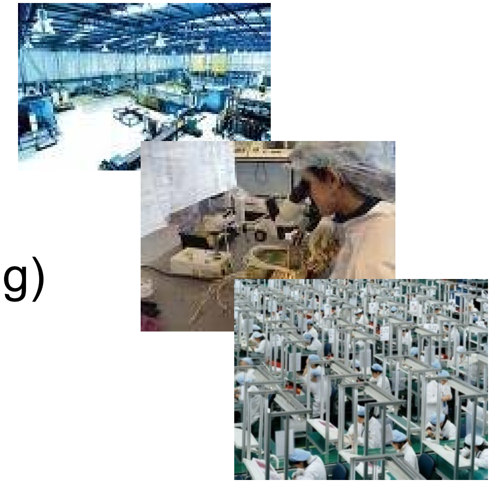
Robustness

- Low sensitivity to temperature variations
- Insensitive to electromagnetic interference



System design

- Simplified system design (no HV, no analog processing)
- Reduced system costs
- Low voltage operation / Reduced power consumption



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