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Color X-ray photon counting image sensor

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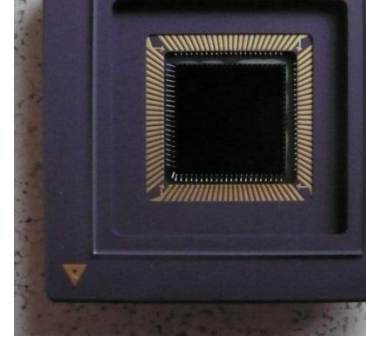
³ Université Paris Nord XIII, France



Vrije Universiteit Brussel

UNIVERSITÉ PARIS 13
NORD

Challenge addressed



An X-ray photon counting pixel array

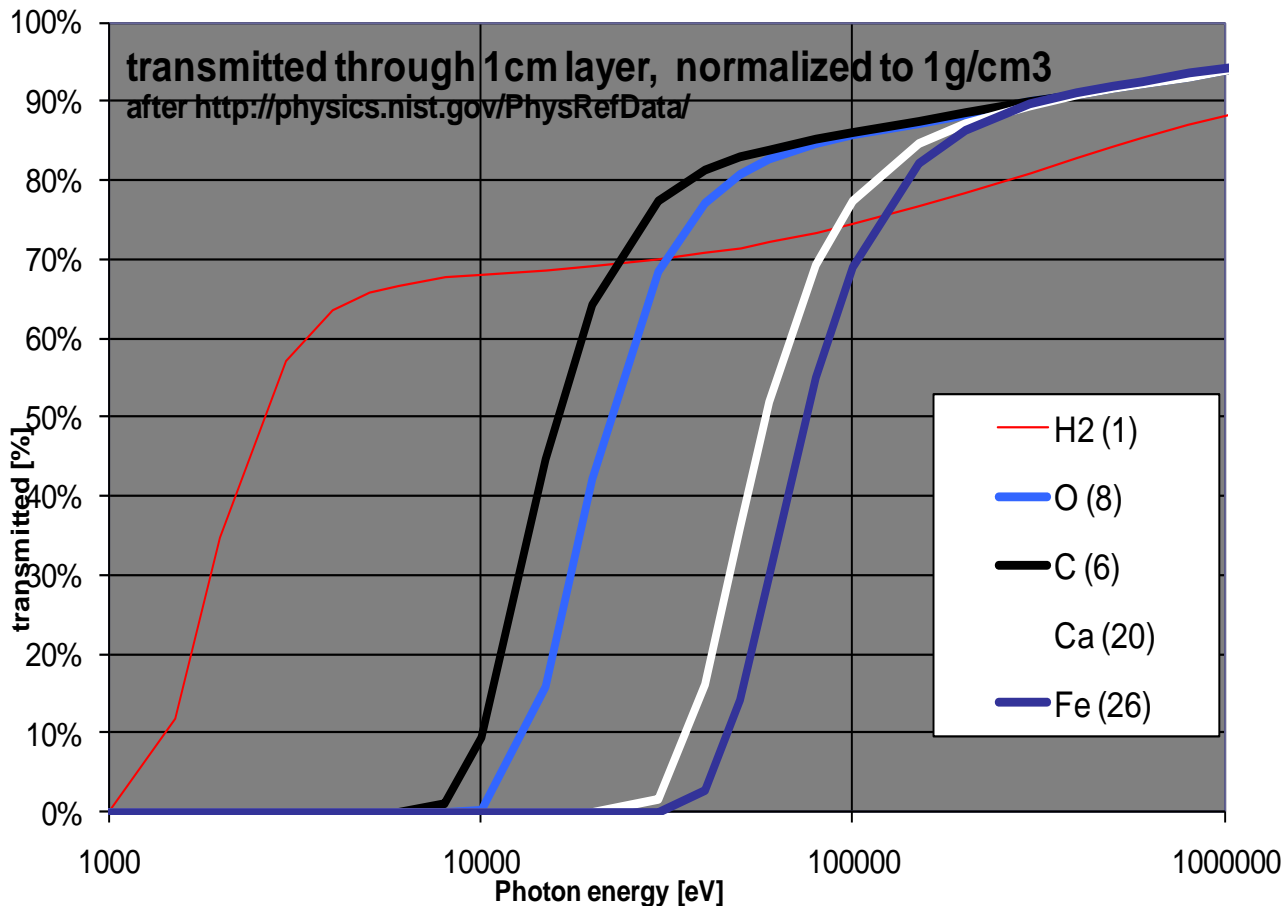
- Indirect (using a “scintillator”) X-ray detection
- Detecting charge packets of 100 to 500 electrons per X-photon
- Counts up to 1000...5000
- Counting speed 100 to 100.000 Hz

Si demonstrator realization as a

- 92x92 pixel array, 100 μ m pixel pitch
- Two channels = COLOR X-ray
- 45 transistors per pixel
- Detection threshold noise & variability $\sim 15e^-_{\text{RMS}}$
- Covered with a GdOS scintillator sheet

BTW

What is “Color” X-ray?



X-ray spectral absorption depends partly on the atomic composition of material.

O=water

C=fat

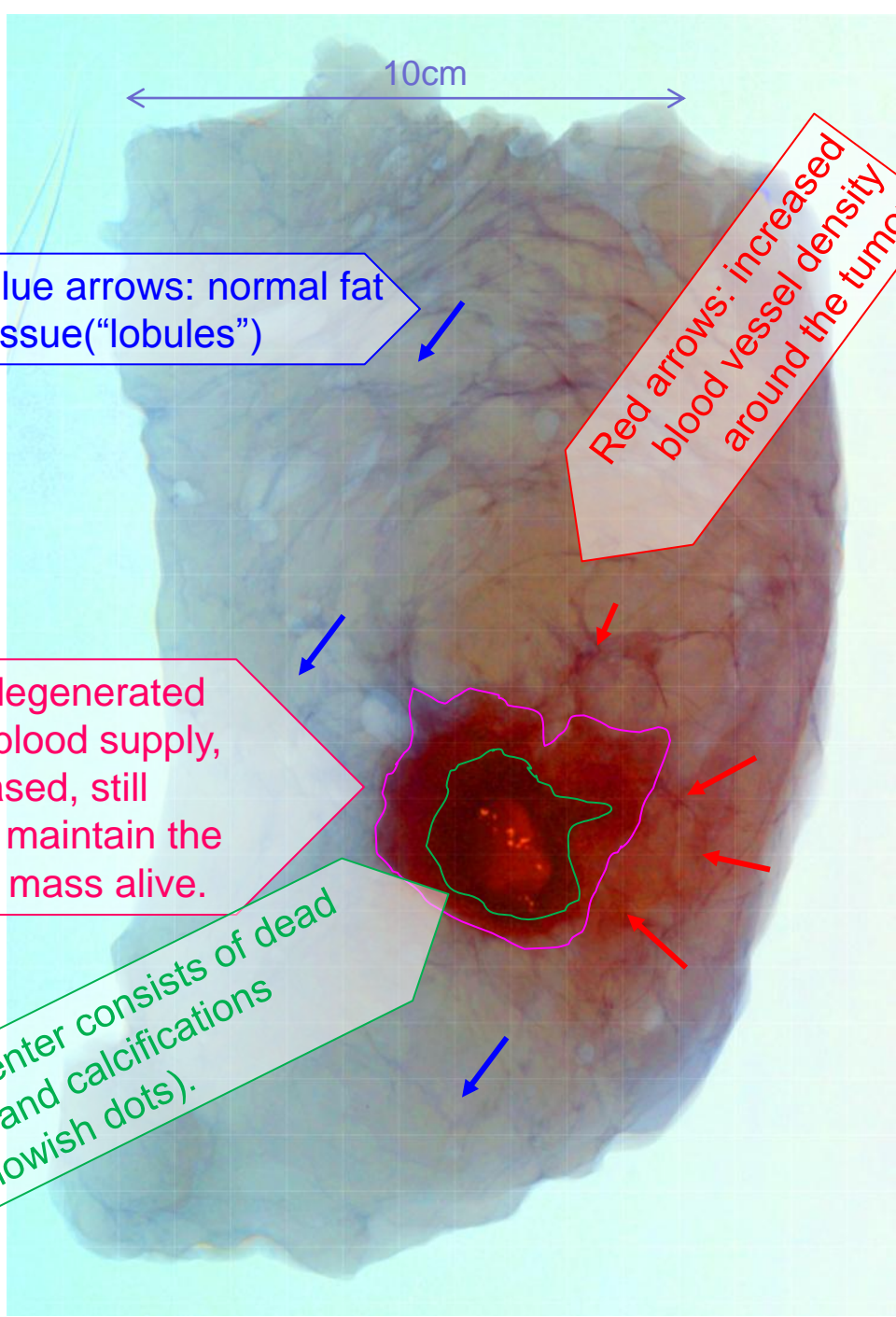
O&C=proteins, cancer, DNA...

Breast carcinoma specimen "Poorly differentiated invasive duct" type.

B. Dierickx, N. Buls, C. Bourgain, C. Breucq, J. Demey, B. Dupont, A. Defornez, "Multi-energy X-ray imaging for mammography", BHPA symposium, Brussels, 5-6 feb 2010

I. Willekens, B. Dierickx, N. Buls, C. Breucq, A. Schiettecatte, J. de Mey, C. Bourgain, "Superiority of multi-energy color X-ray for breast specimen radiography", European Society for Radiography, Vienna, March 2011

Courtesy of and in collaboration with



blue arrows: normal fat tissue ("lobules")

Red arrows: increased blood vessel density around the tumor

the tumor is degenerated because the blood supply, though increased, still insufficient to maintain the whole cancer mass alive.

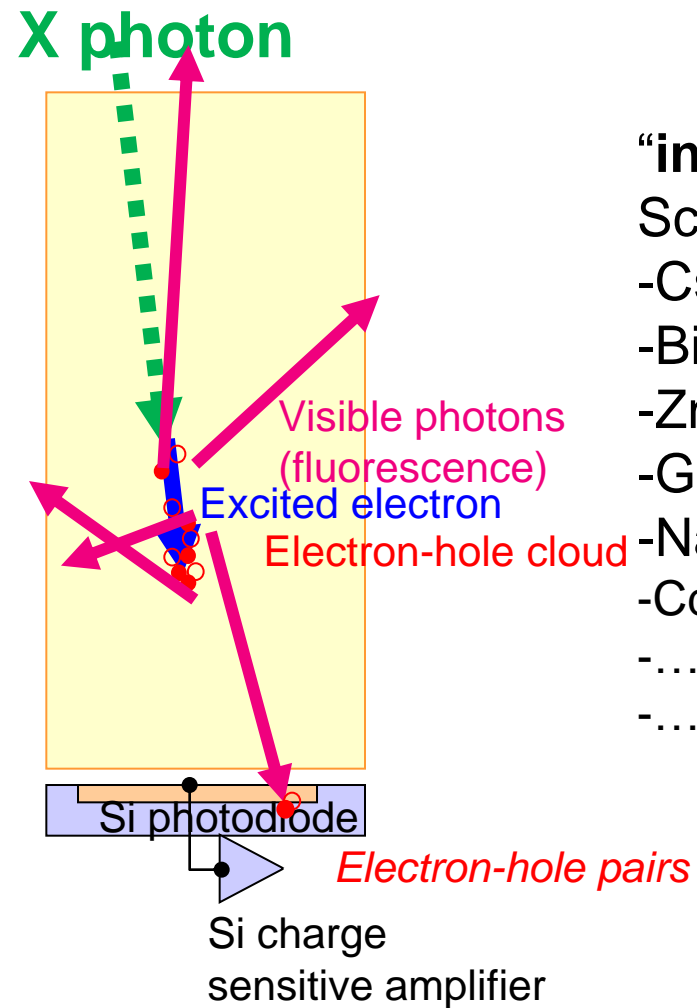
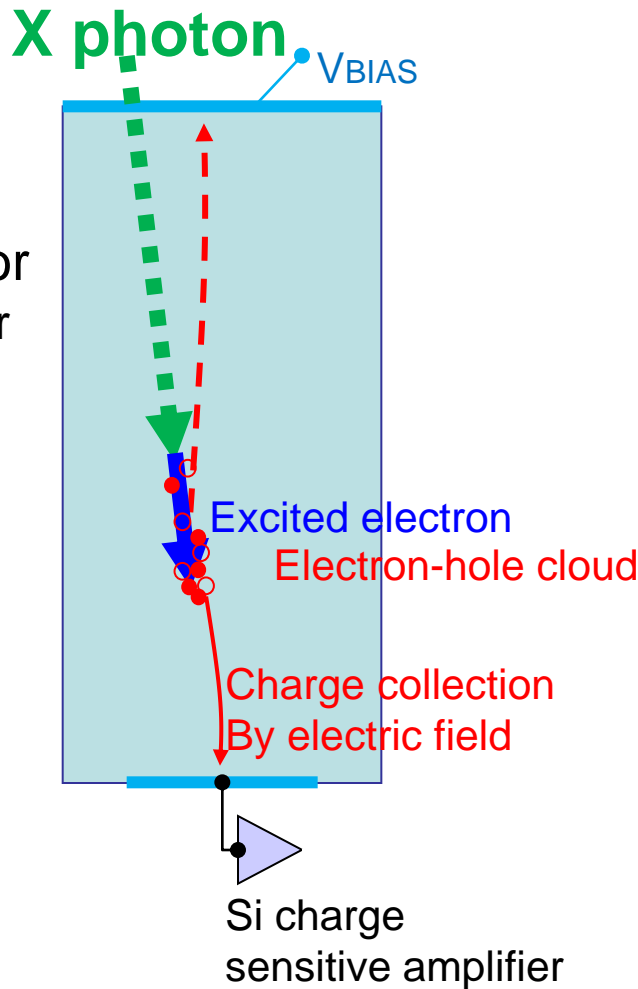
The center consists of dead cells and calcifications (yellowish dots).

Outline

- What is color X-ray
- Direct and indirect X-ray detection**
- Indirect Photon counting pixel concept and layout
- Pixel key subcircuits
- Measurement results & performance
- Future developments and conclusions

Direct and Indirect X-ray detection pixel

Direct detector
 =semiconductor
 -Si
 - α Se
 -InP
 -CdTe
 -CdZnTe
 -...



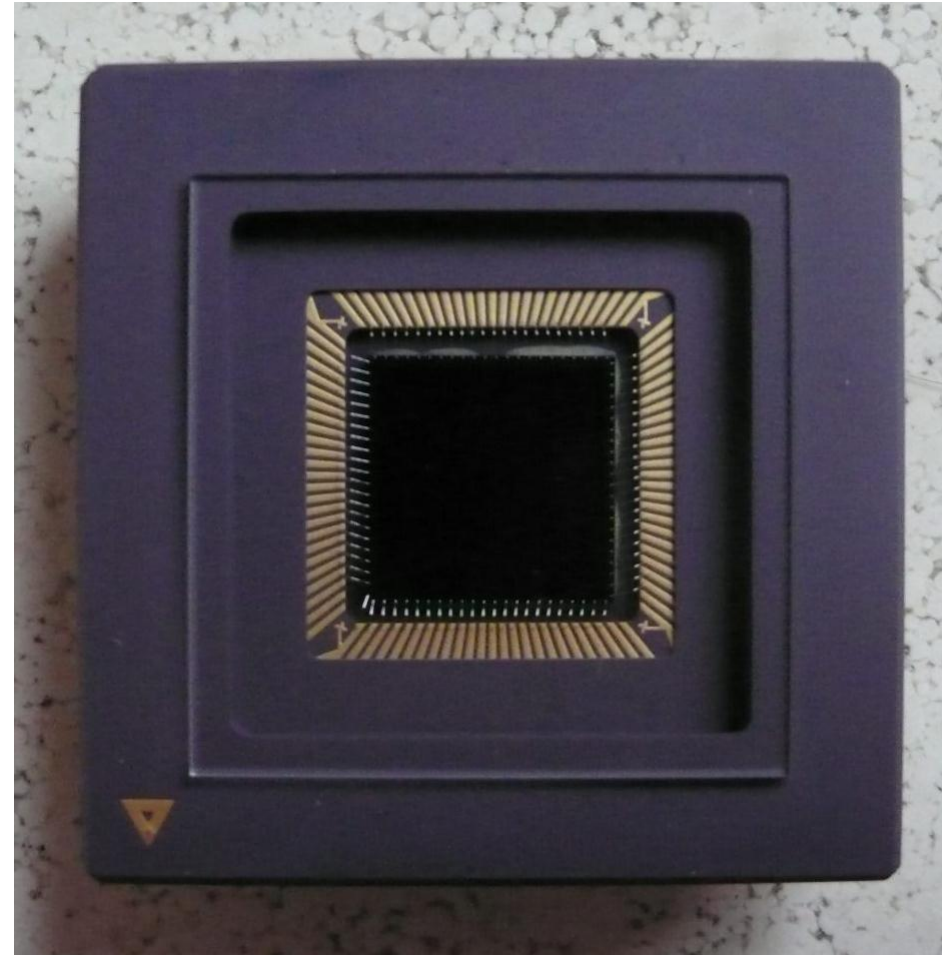
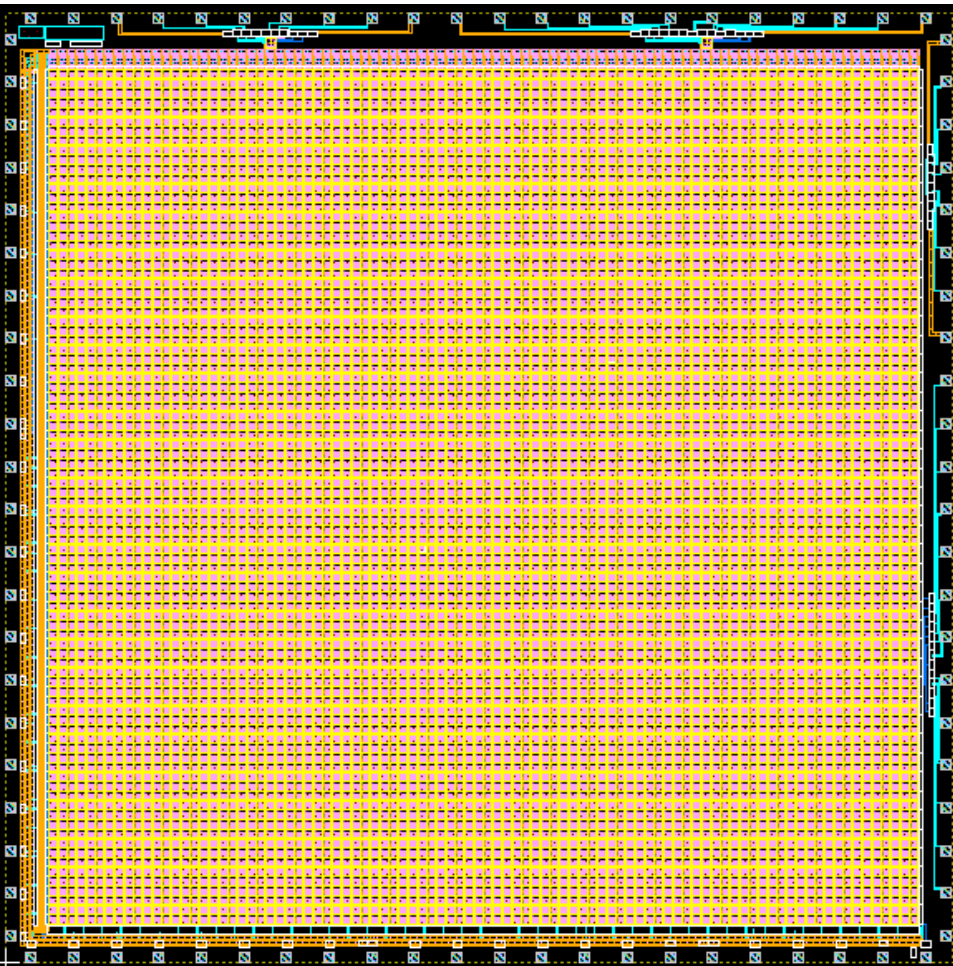
“indirect”=
 Scintillator
 -CsI
 - $\text{Bi}_4\text{Ge}_3\text{O}_{12}$
 -ZnSe
 - $\text{Gd}_2\text{O}_2\text{S}$
 - NaBiW_2O_8
 - CdWO_4
 -...
 -...

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Photon counting pixel array

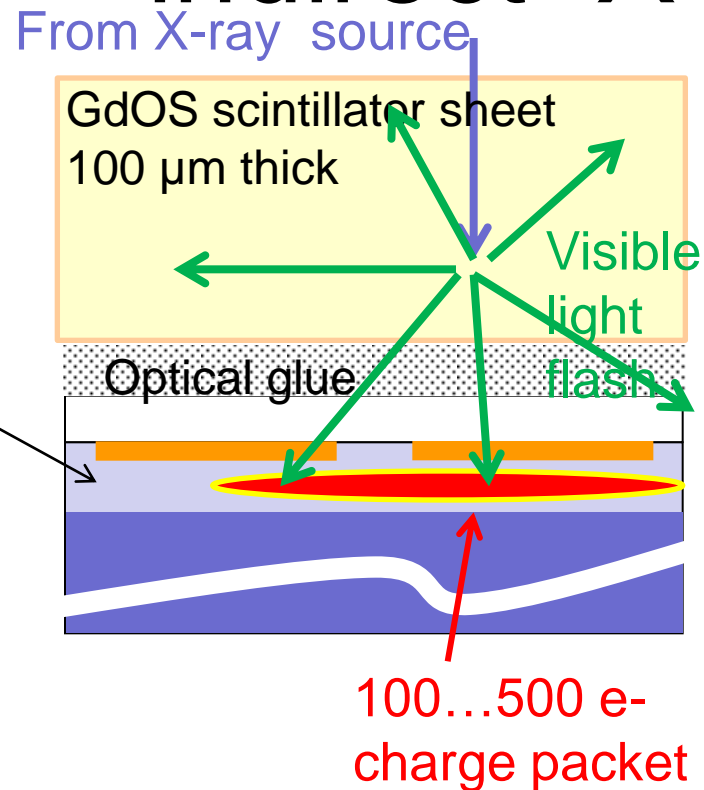
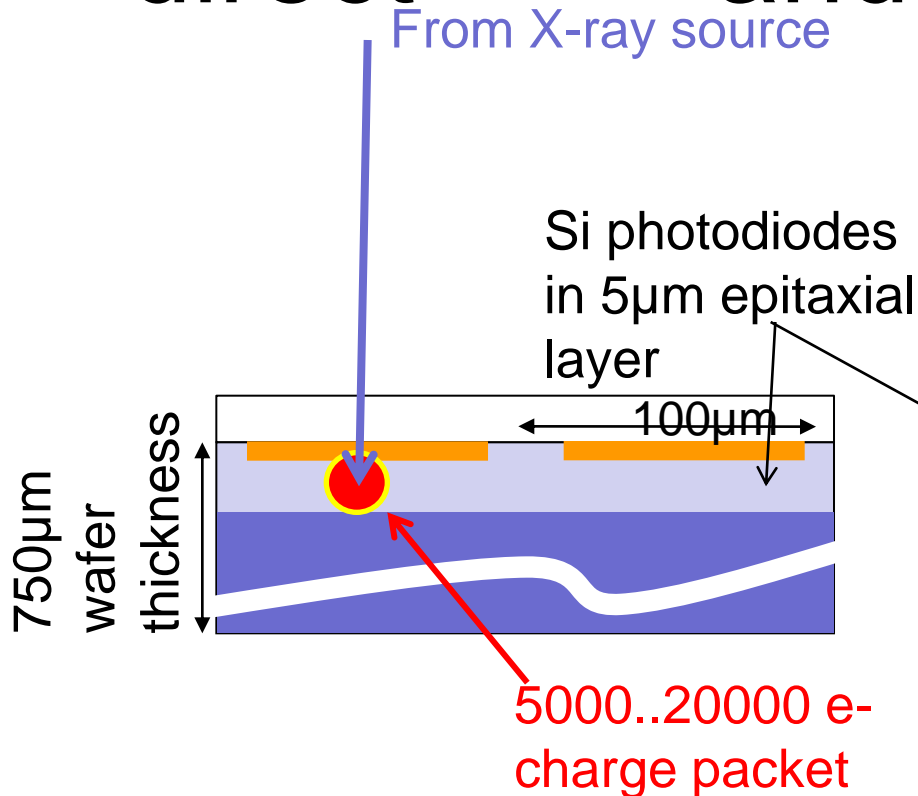
QX2010: 100 μm pitch
92x90 pixels



Pixel sees both

“direct” and

“indirect” X



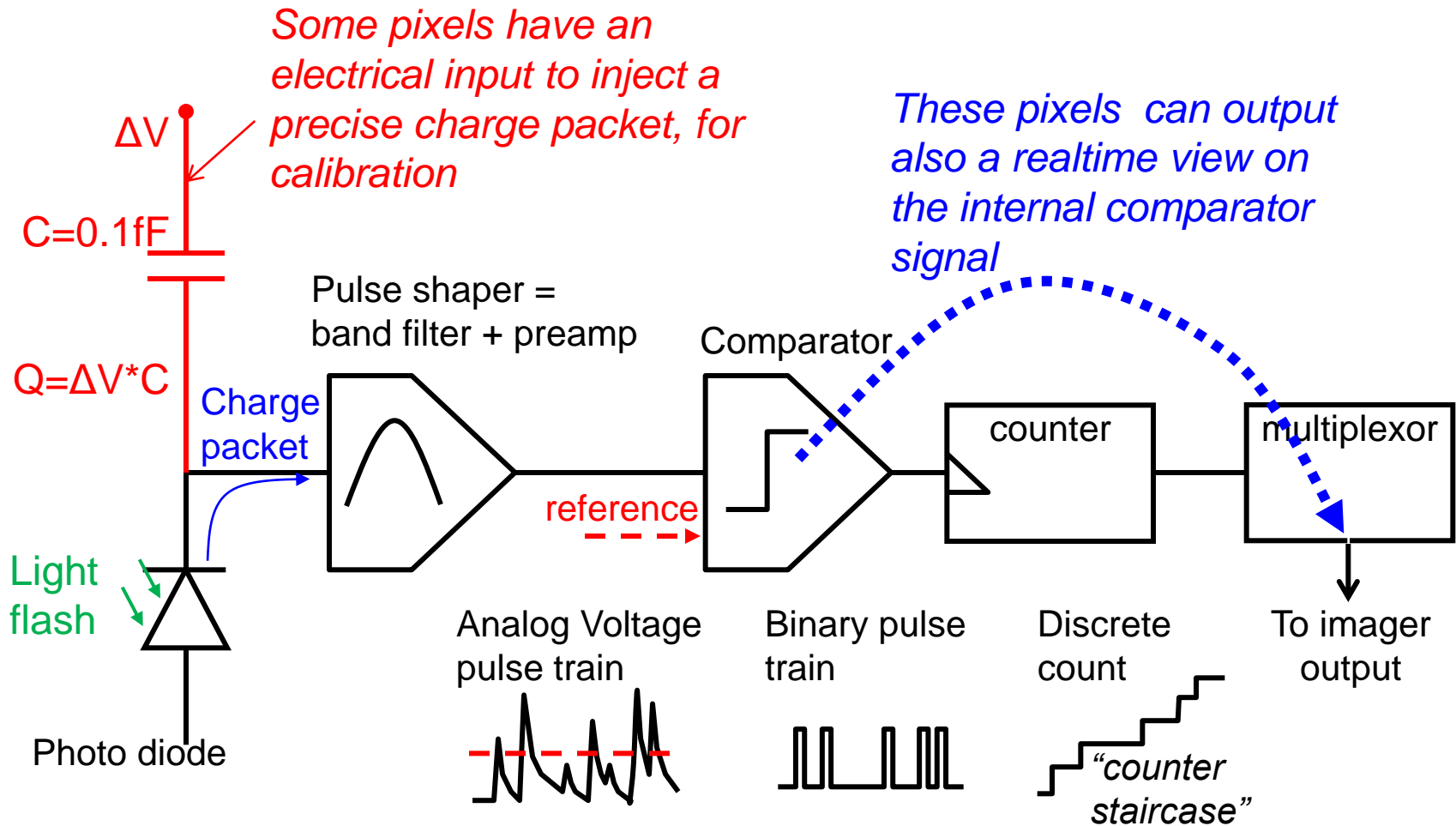
Direct detection:

- Rare in Si, “spurious”
- Localized and large charge packet

Indirect detection:

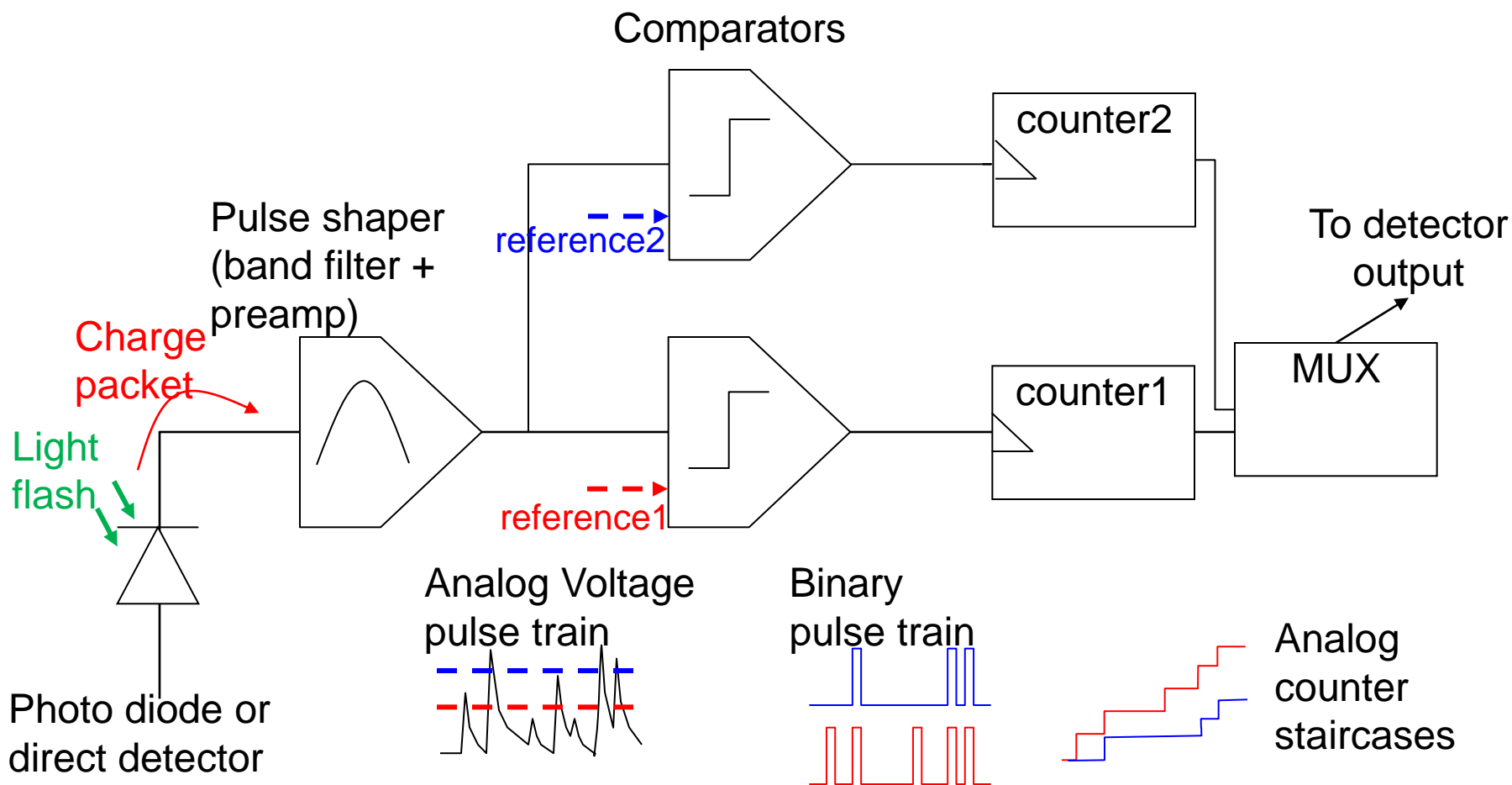
- “efficient” in high-Z scintillator
- Indirect charge packet is small and smeared out

X-photon counting pixel topology



Color X-ray

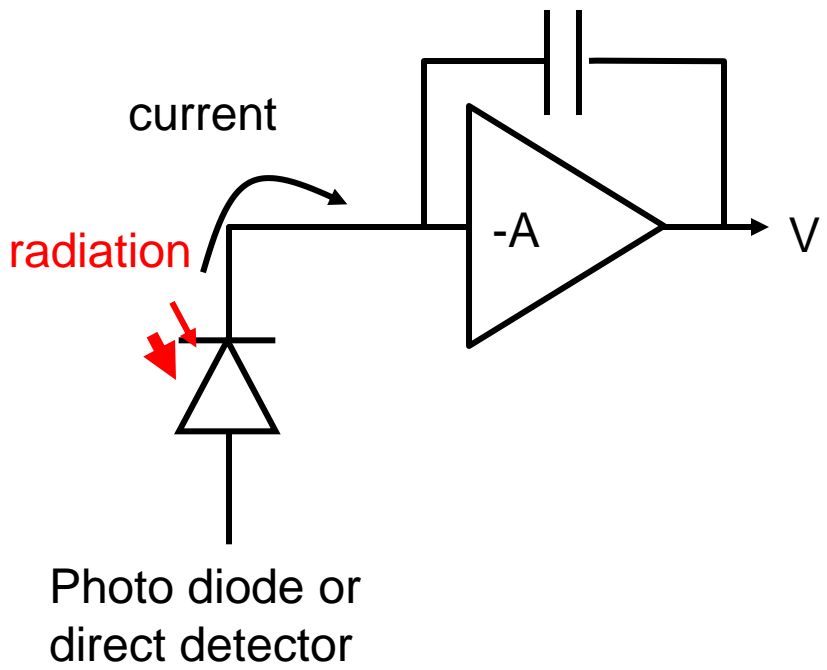
photon counting pixel concept



Outline

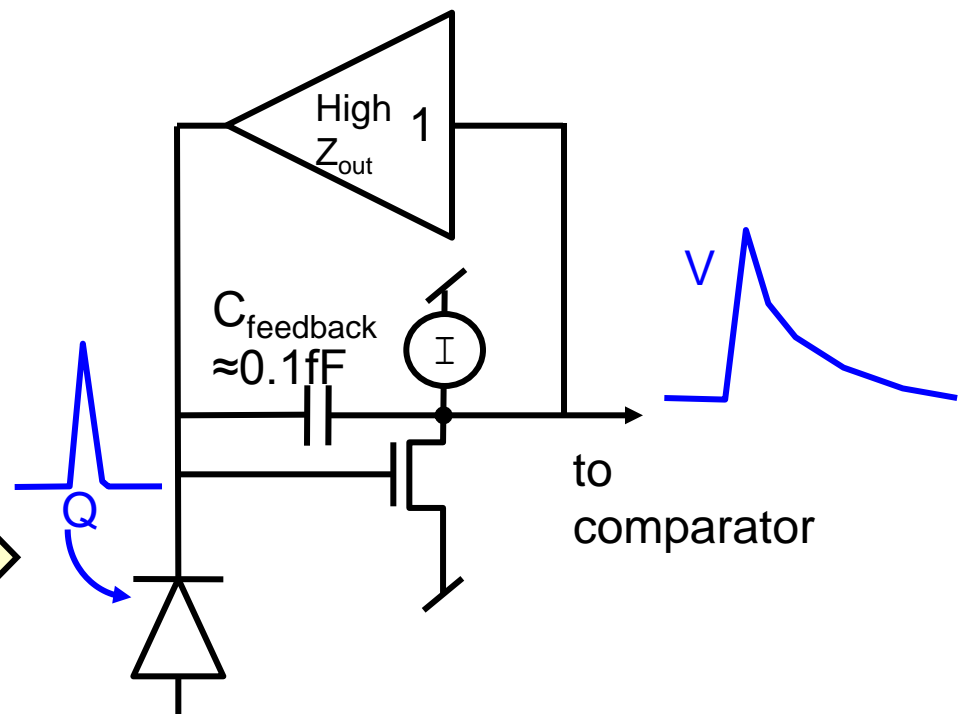
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Charge integrator (CTIA)

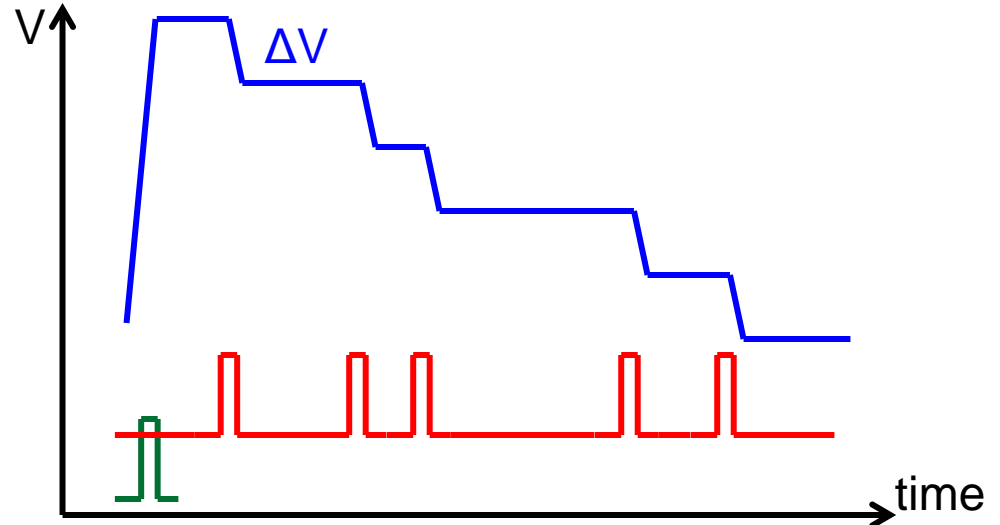
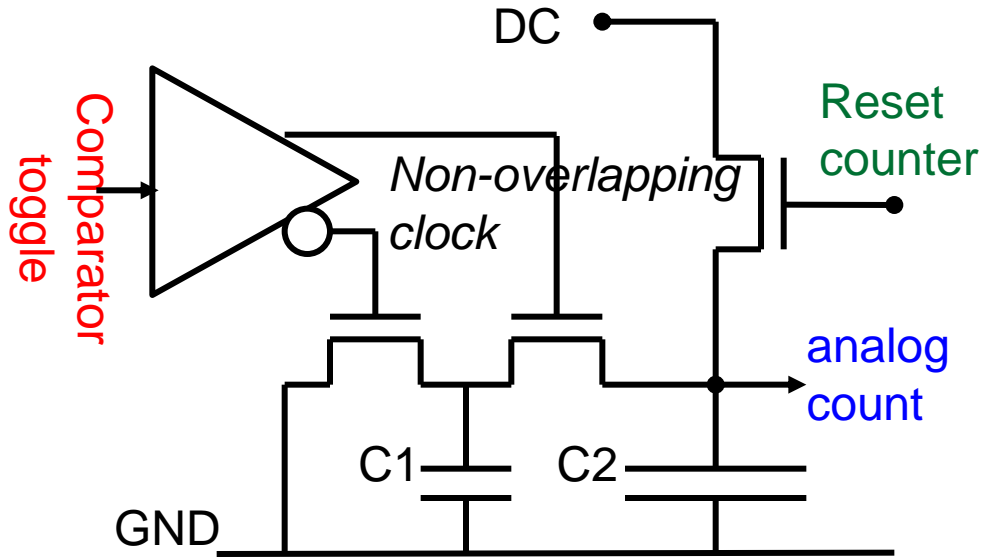


General concept
charge sensitive amplifier
Integrate charges without seeing individual photons

Actual concept
charge sensitive amplifier
CTIA with resistive feedback
= "pulse shaper"

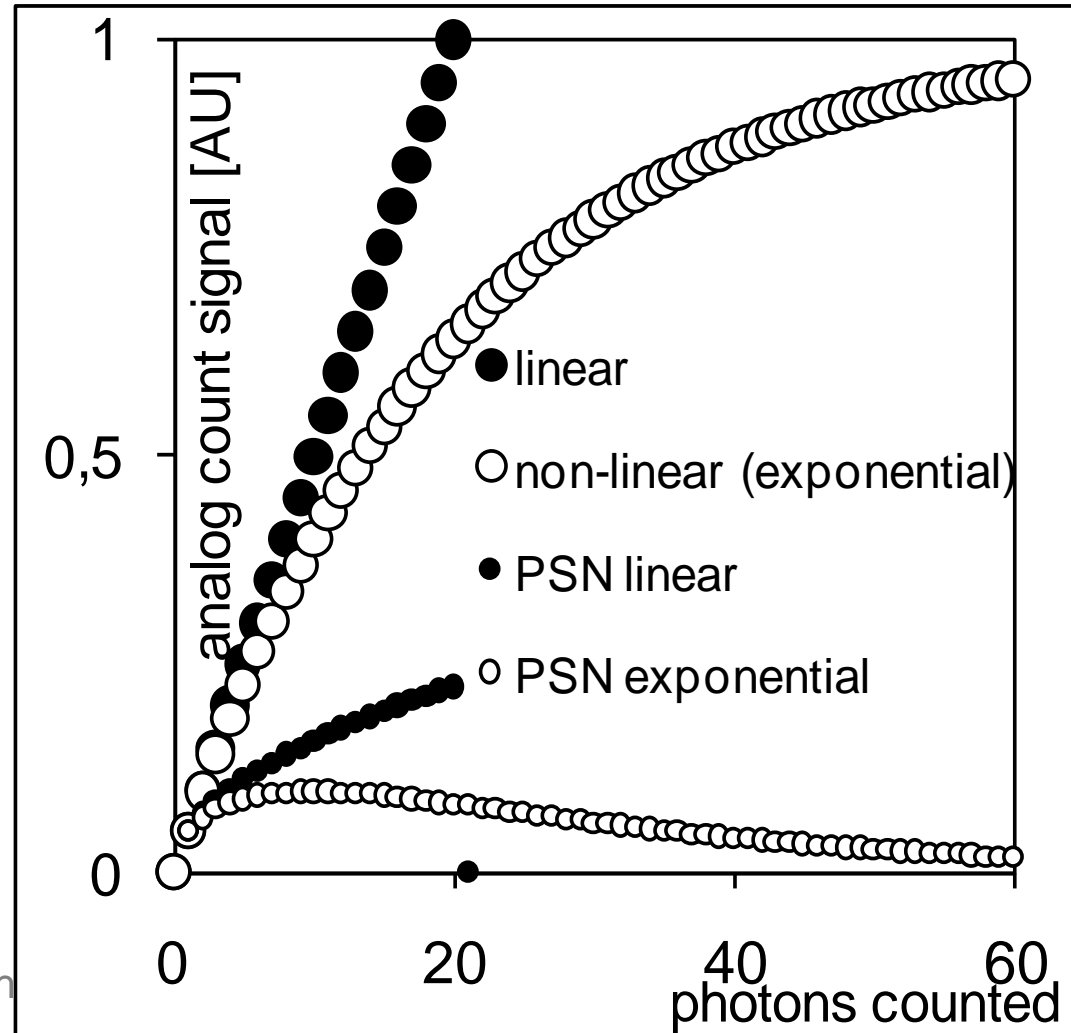


Very compact *analog* counter



Non-linear analog counting

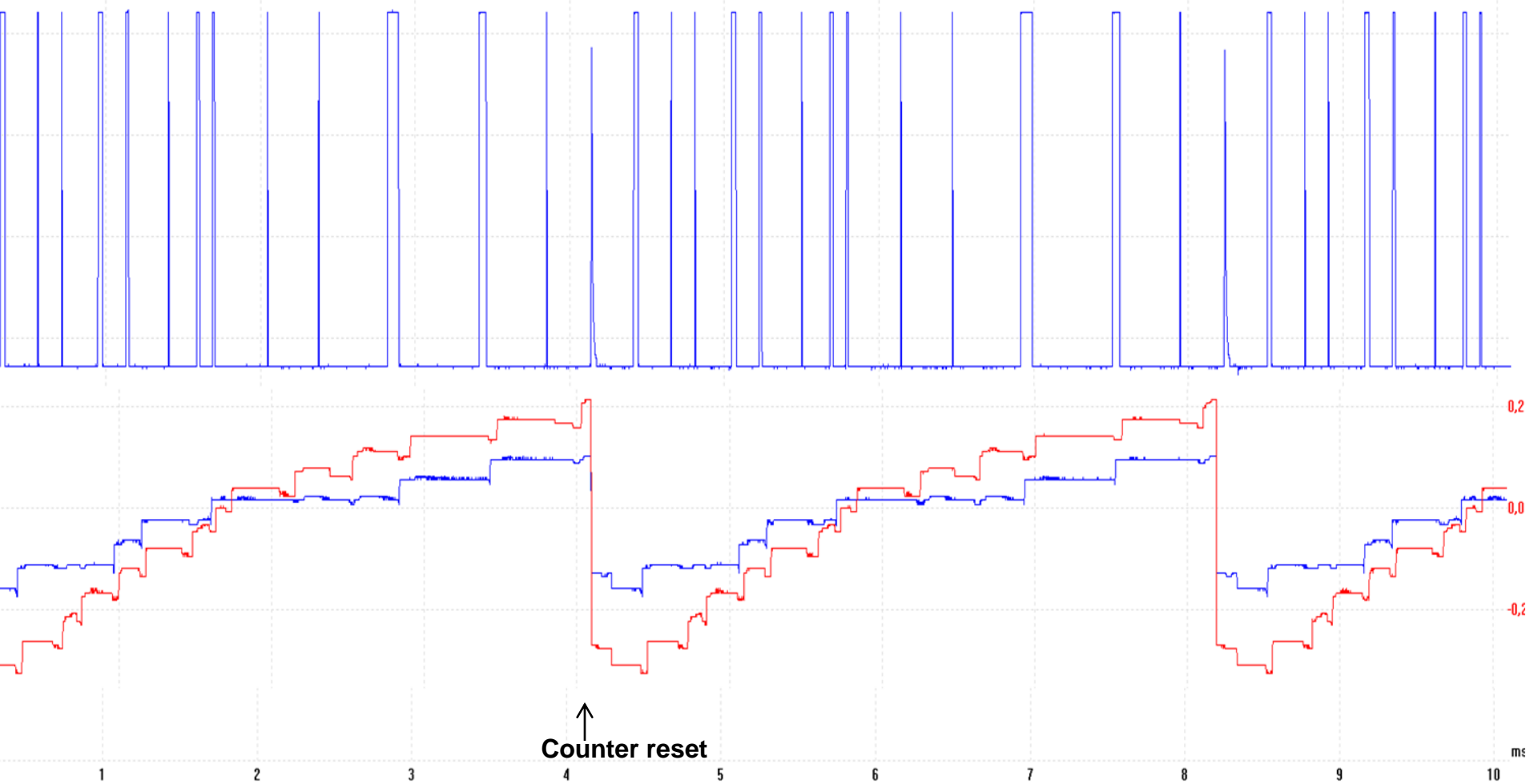
“Analog” counting is valid as long as ΔV is visible by an external ADC’s LSB, or photon shot noise > ADC LSB



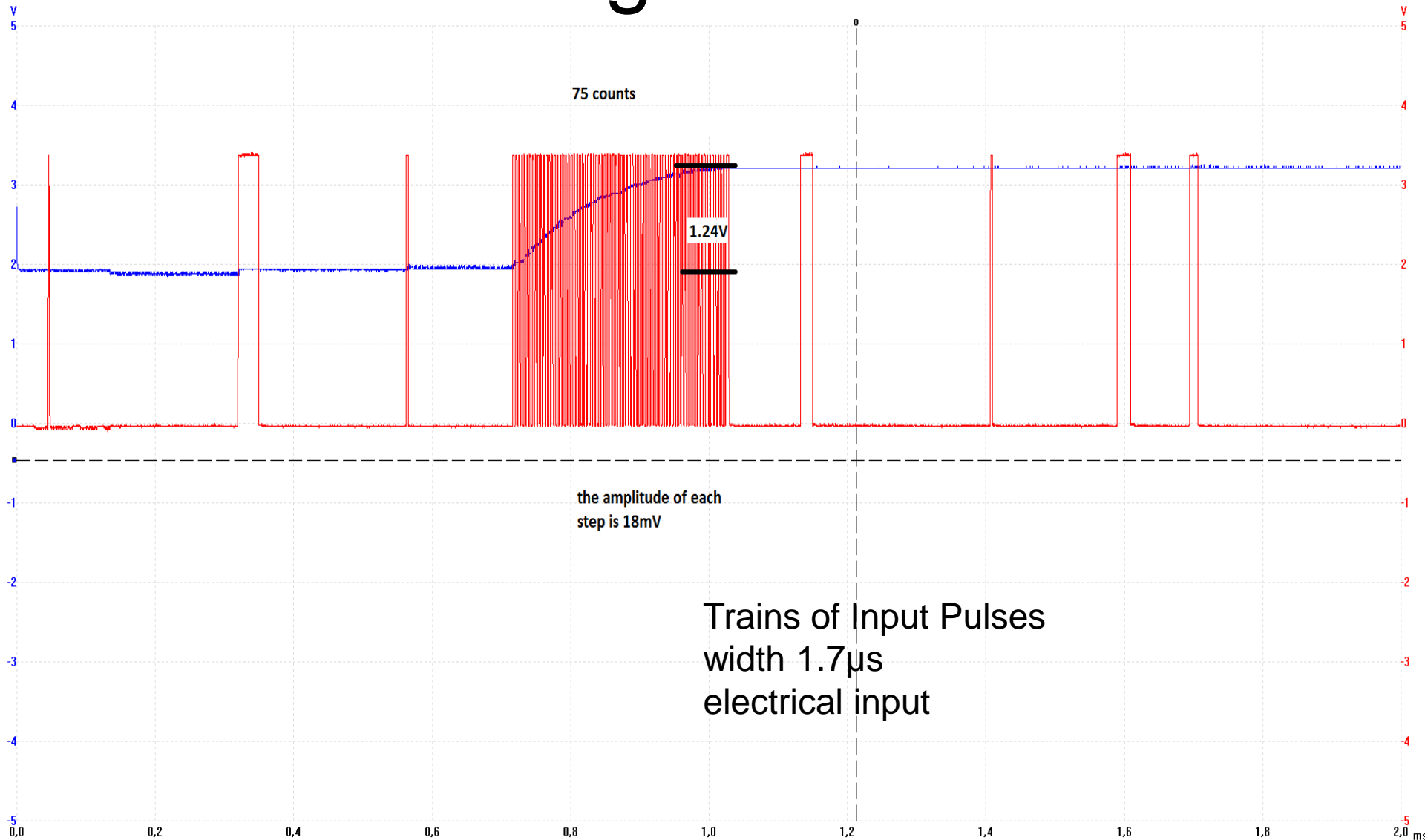
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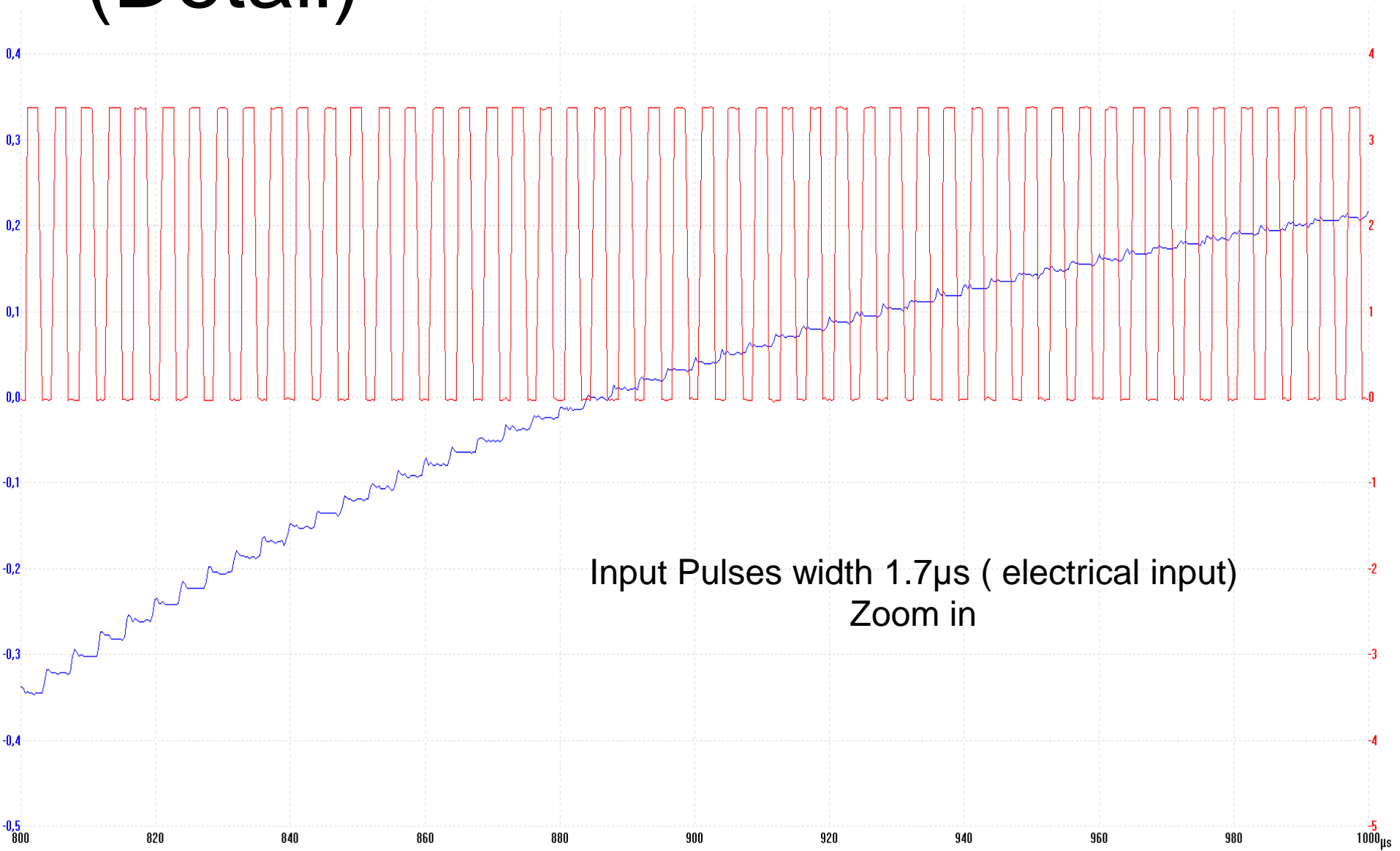
Counting wide and small LED pulses



Demonstrating non-linear count



(Detail)



9 June 2011

Color X-ray photon counting image sensor

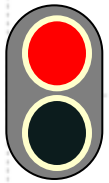
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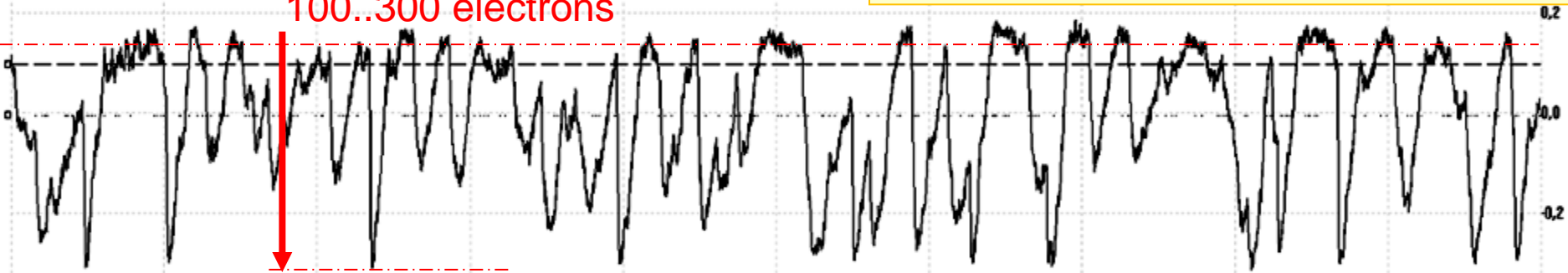
X-ray illumination: comparators's real time signal

X-ray source: 70kVp, 1mA
Beam hardened with 1/2mm Cu
Distance 1.5m
Scintillator: GdOS 100 μ m thick
Photon rate is about 0.5 X-photon/ms

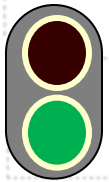
BEAM ON



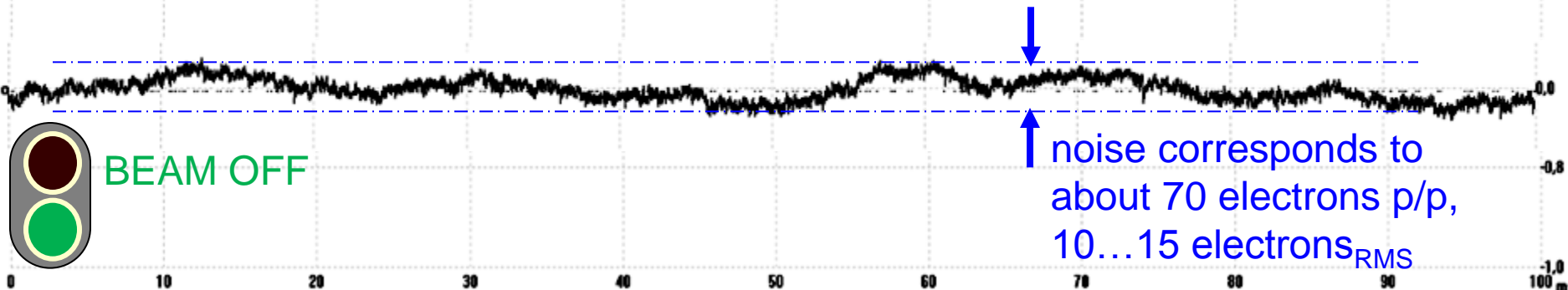
Peaks correspond to
100..300 electrons



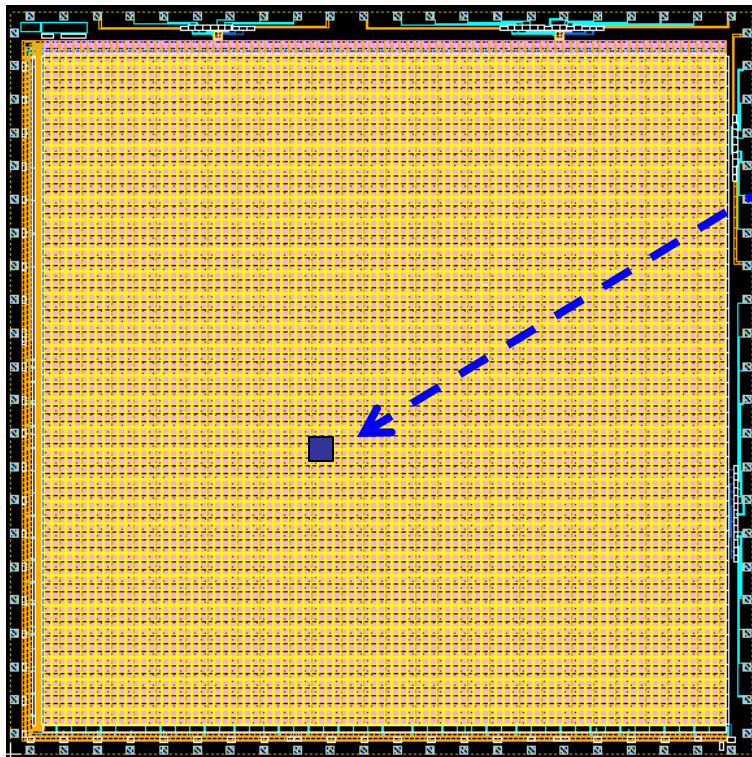
BEAM OFF



noise corresponds to
about 70 electrons p/p,
10...15 electrons_{RMS}



One of the key performance parameters: electrical crosstalk



- 90x92 pixels under pulsed LED illumination
 - One pixel @ (40,40) is covered with metal shield
 - All pixels see the LED and output the same pulse train
- **shielded pixel is quiet**

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Conclusions

Indirect color X-ray photon counting demonstrated

- Pixel has two “energy” channels
- Detects and counts charge packets $<100e^-$
- Pixel has 45 MOSFETs
- Pixel has $\sim 75..80\%$ fill factor
- Good suppression of electrical crosstalk

Future challenges

- X-ray illumination images
- Increasing array size
- Improving performance (noise, speed)
- Enhancing functionality ($>2\text{Mhz}$ countrate)

Thank you

Acknowledging for the
X-ray experiments

