Indirect X-ray photon counting image sensor with 27T pixels and 15 electrons$_{RMS}$ accurate threshold

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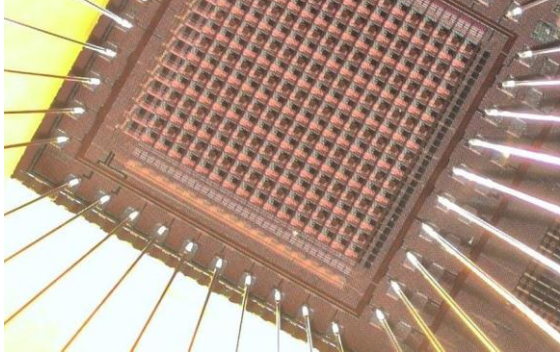
Challenge addressed



An X-ray photon counting pixel array

- Indirect (using a “scintillator”) X-ray detection
- Charge packet = 100 to 500 electrons per X-photon
- Counts up to 1000…5000
- Counting speed 100 to 100.000 Hz

Si demonstrator realization as a

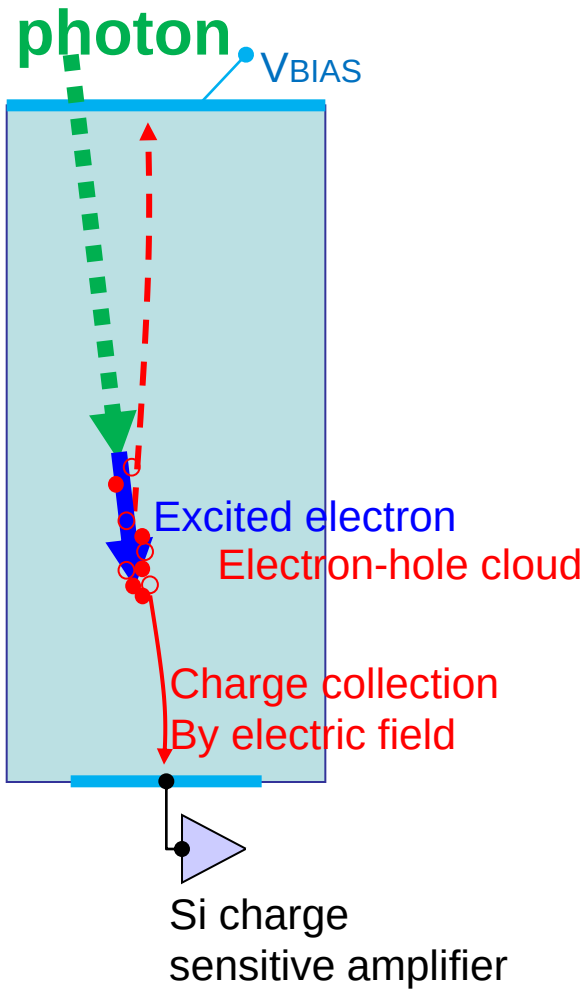
- 16x16 pixel array, 100µm pixel pitch
- 27…40 transistors per pixel (8 variants)
- Detection threshold noise & variability ~15e^-_{RMS}
- Covered with a GdOS scintillator sheet

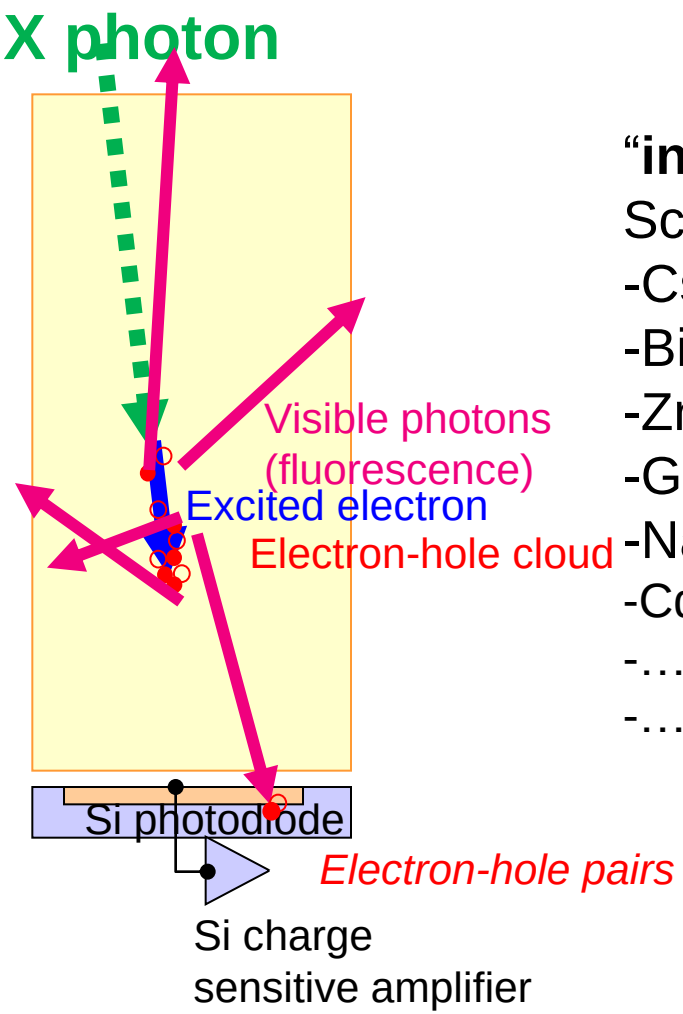
Outline

- ☑ 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
-$Bi_4Ge_3O_{12}$
-ZnSe
-Gd_2O_2S
-$NaBiW_2O_8$
-$CdWO_4$
-…
-…

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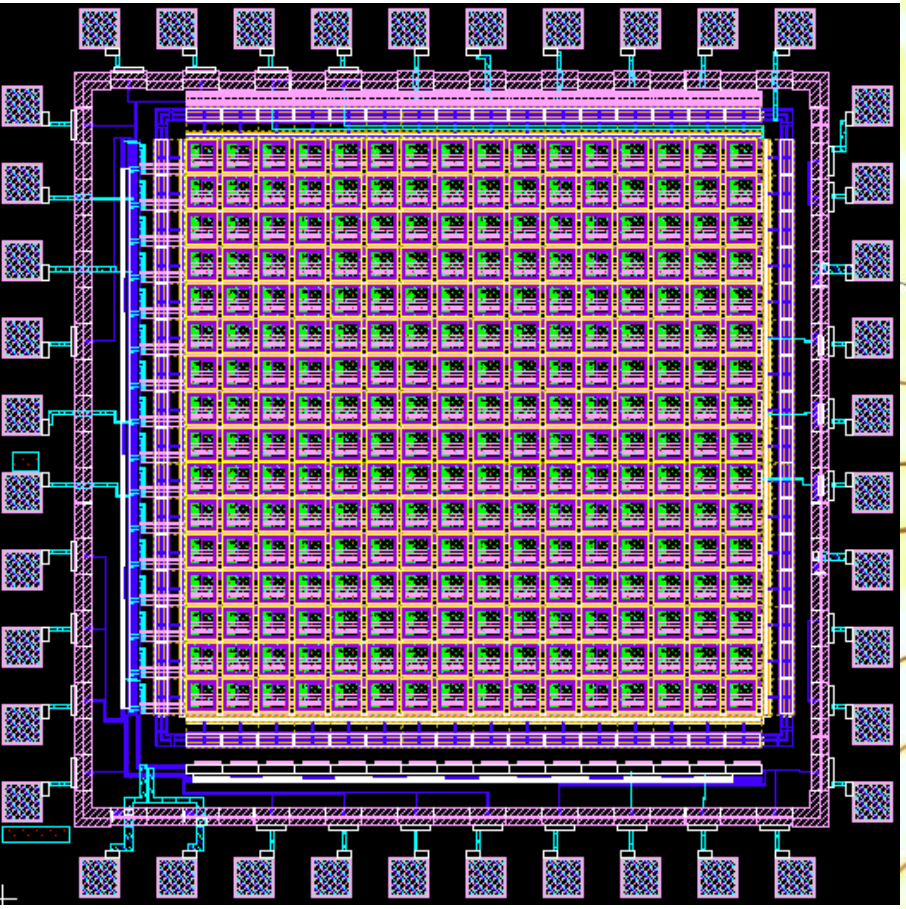
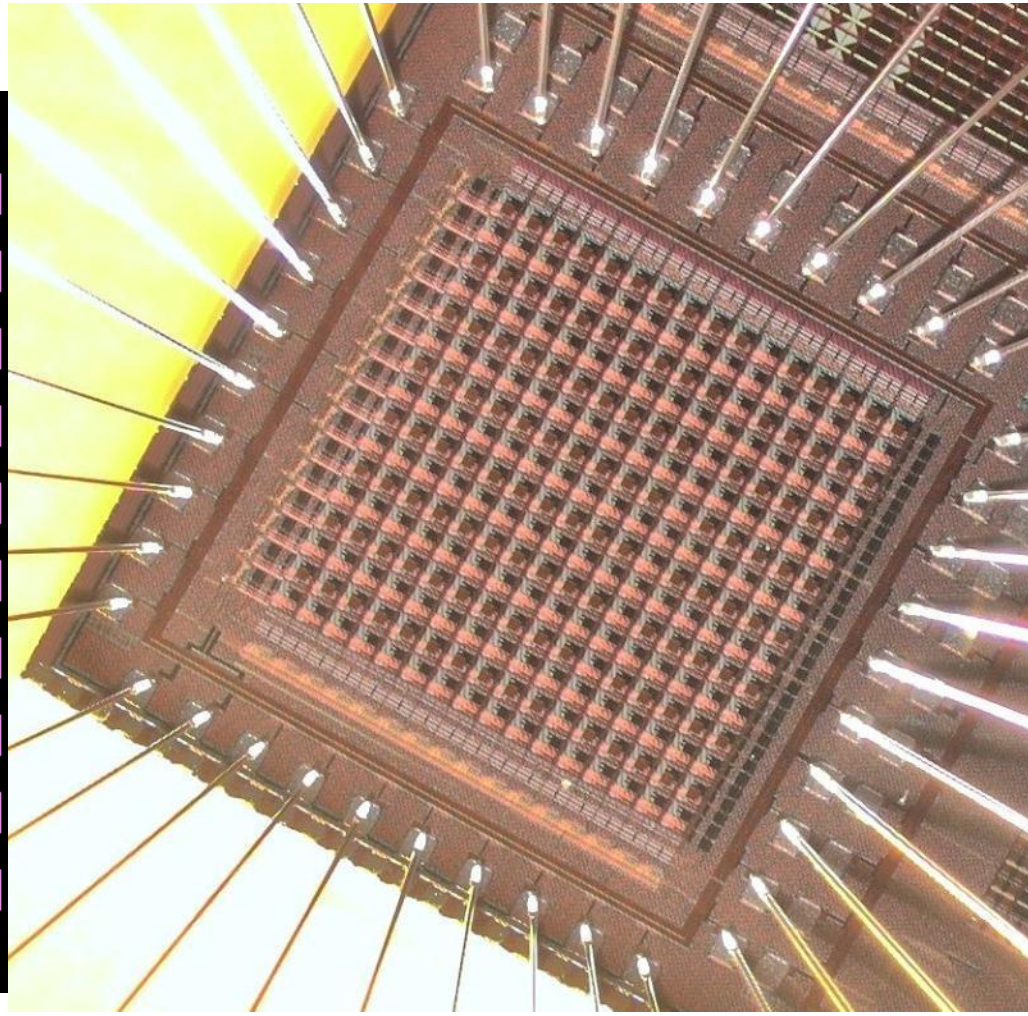
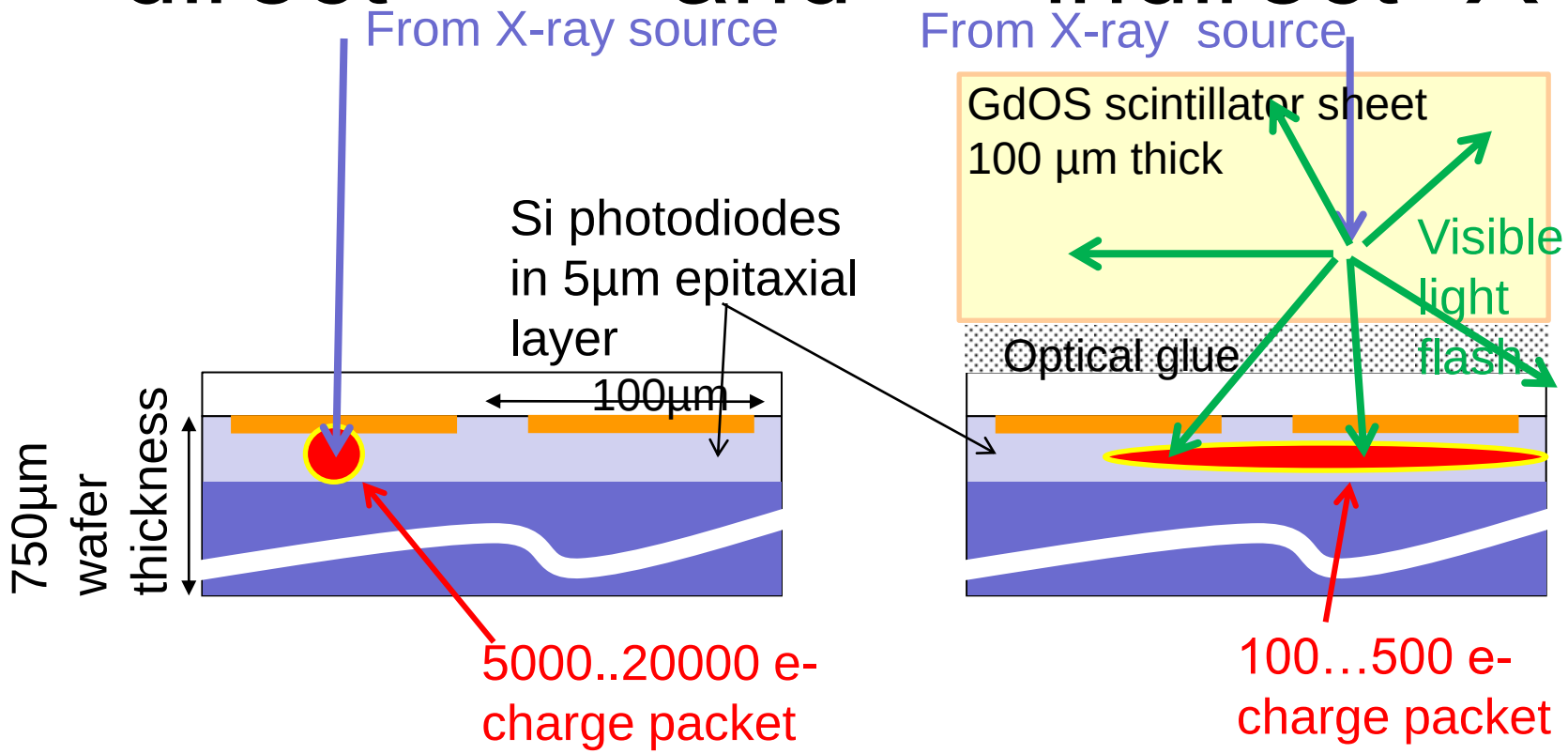
First generation of 2D photon counting pixel array





Pixel sees both "direct" and "indirect" X



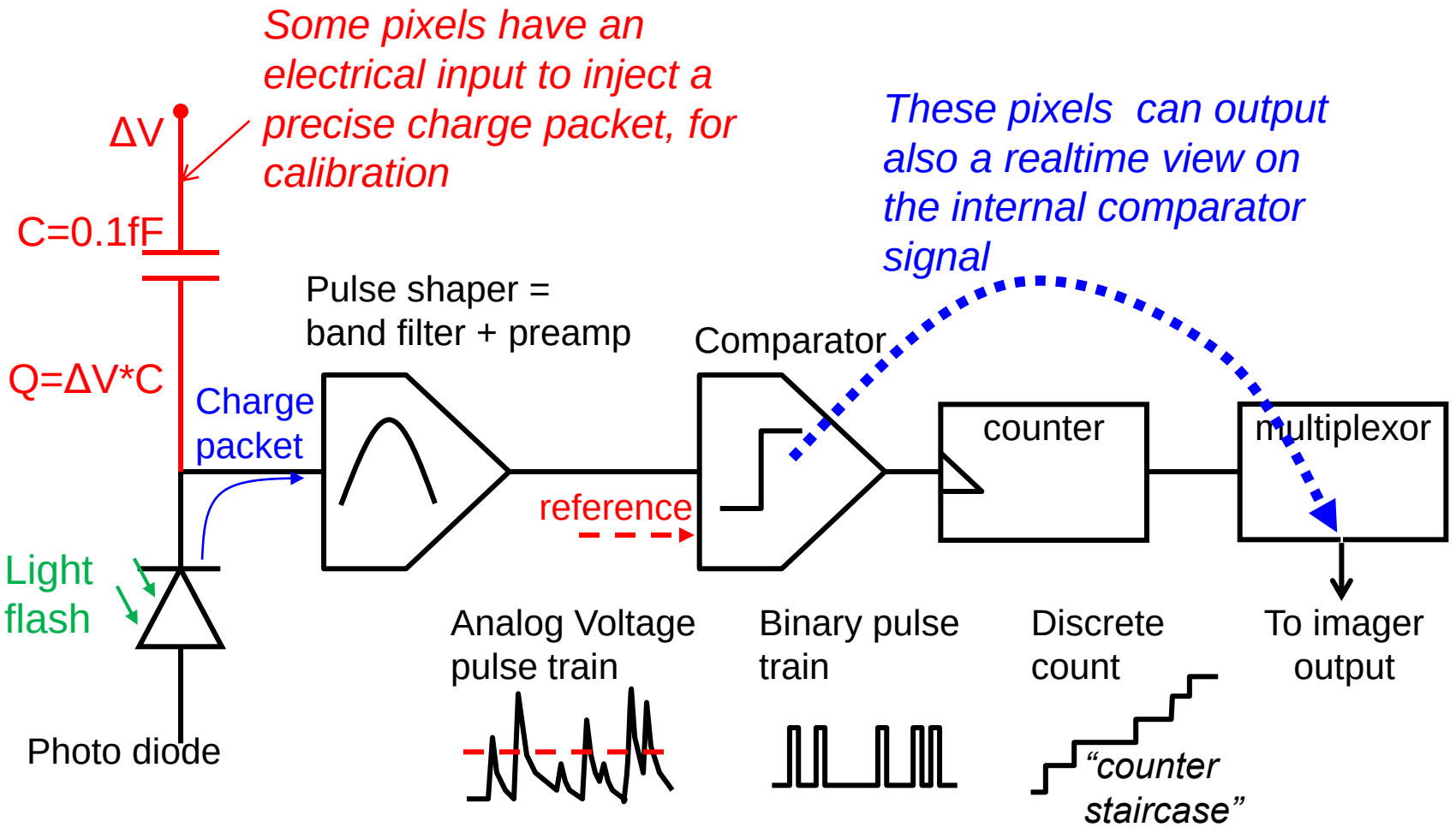
Direct detection:

- Rare in Si, "spurious"
- Localized and large charge packet

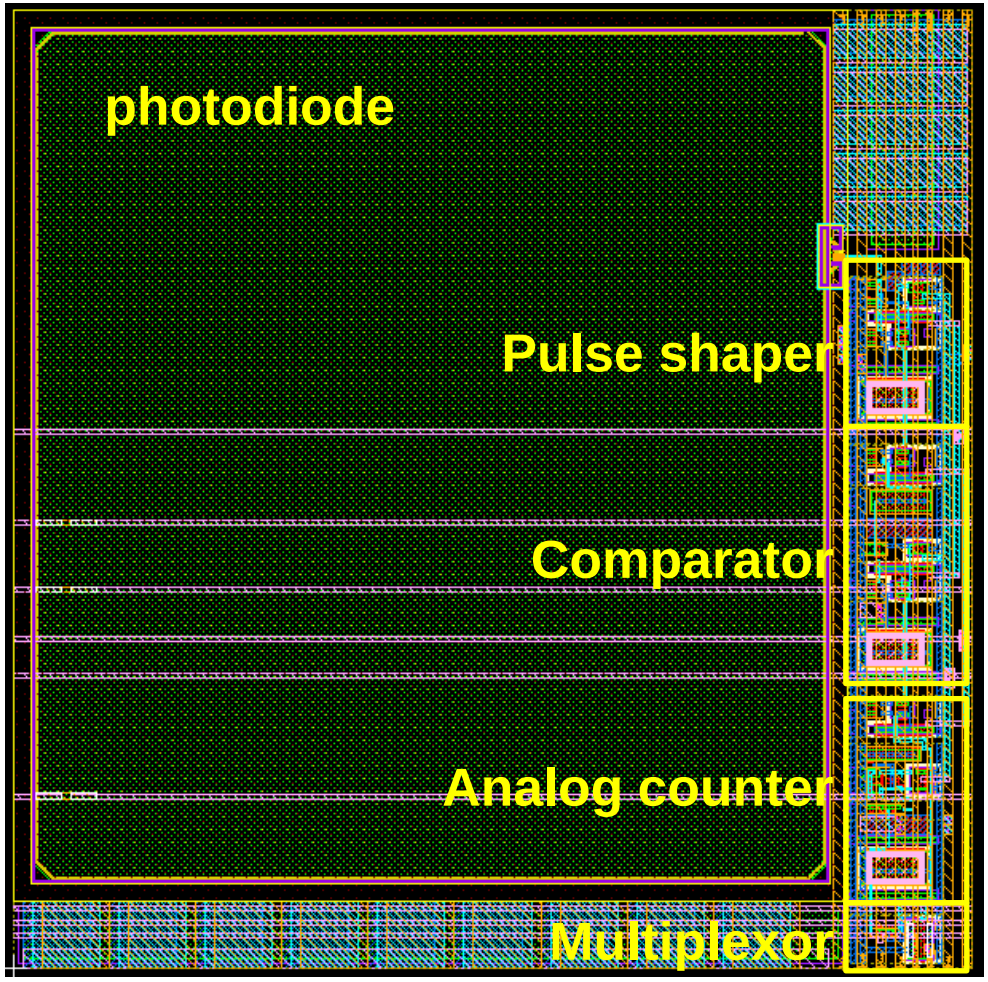
Indirect detection:

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

X-photon counting pixel topology



Pixel layout



- 100µm pitch
- 0.18µm CMOS technology
- 75..80% FF
- Variants with 27…40 MOSFETs

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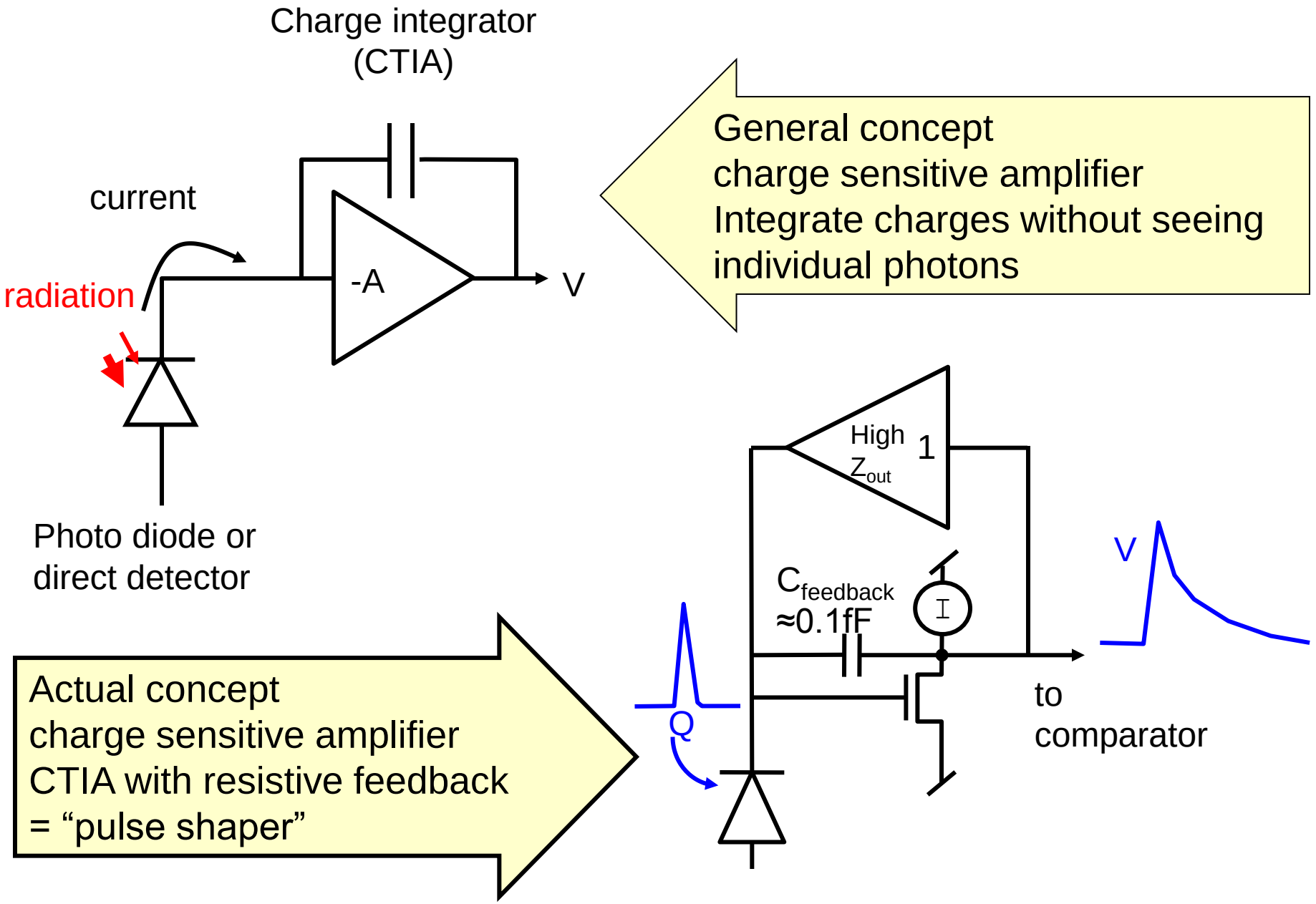
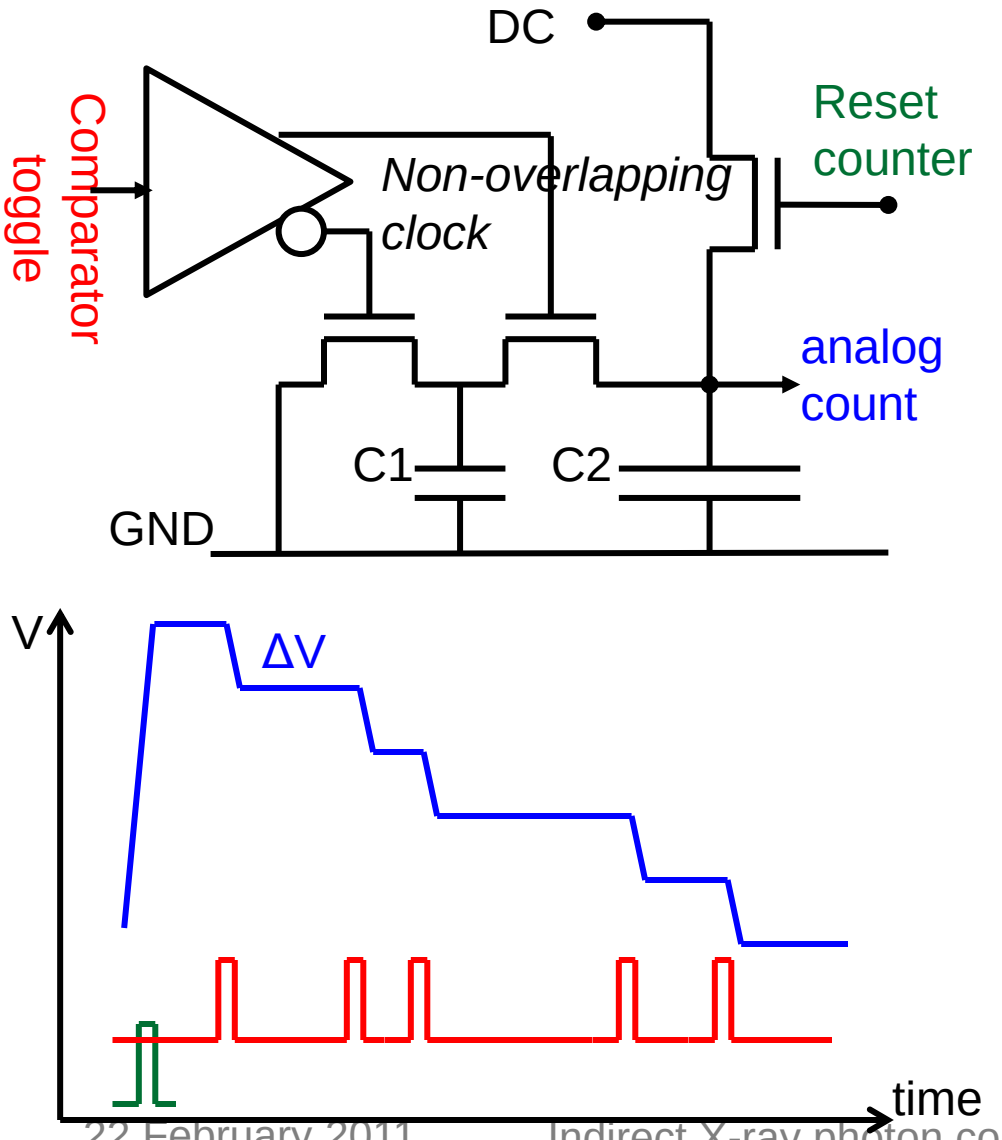
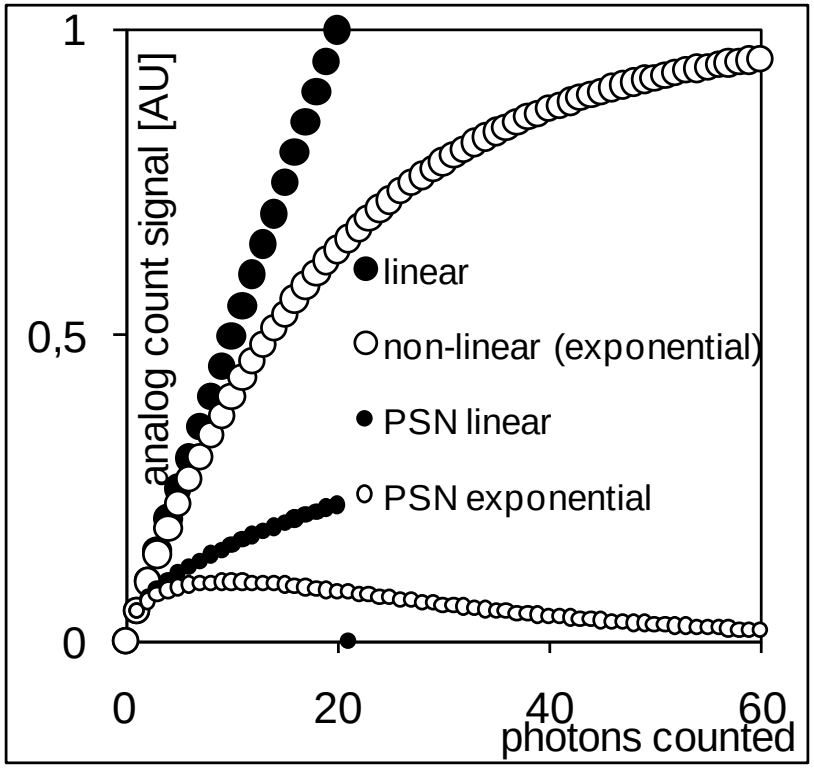

Charge integrator
(CTIA)
current
radiation
-A
V
Photo diode or
direct detector
General concept
charge sensitive amplifier
Integrate charges without seeing
individual photons
High
Z_out
1
C_feedback
≈0.1fF
I
V
Q
to
comparator
Actual concept
charge sensitive amplifier
CTIA with resistive feedback
= “pulse shaper”

Very compact *analog* counter



"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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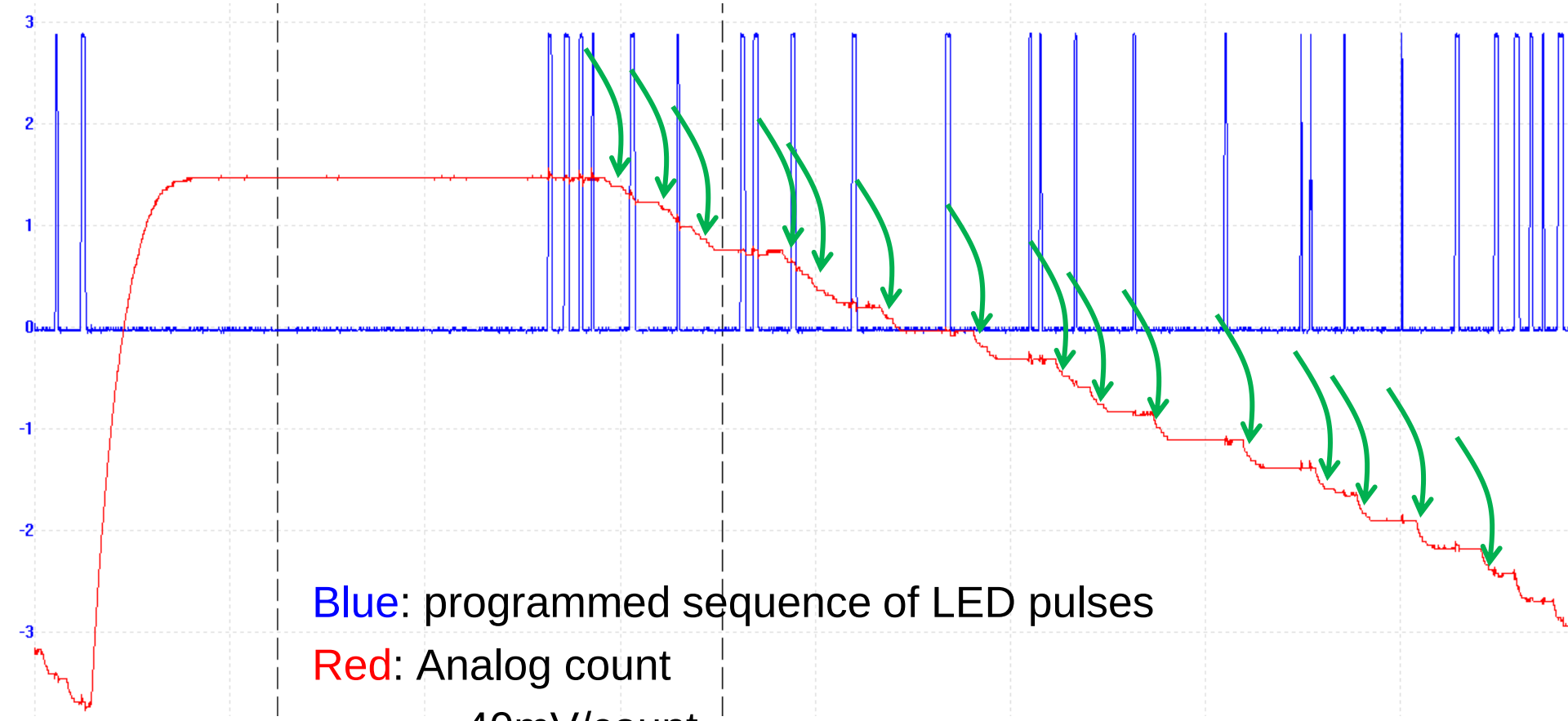
Under LED illumination: pixel's analog count



Blue: programmed sequence of LED pulses

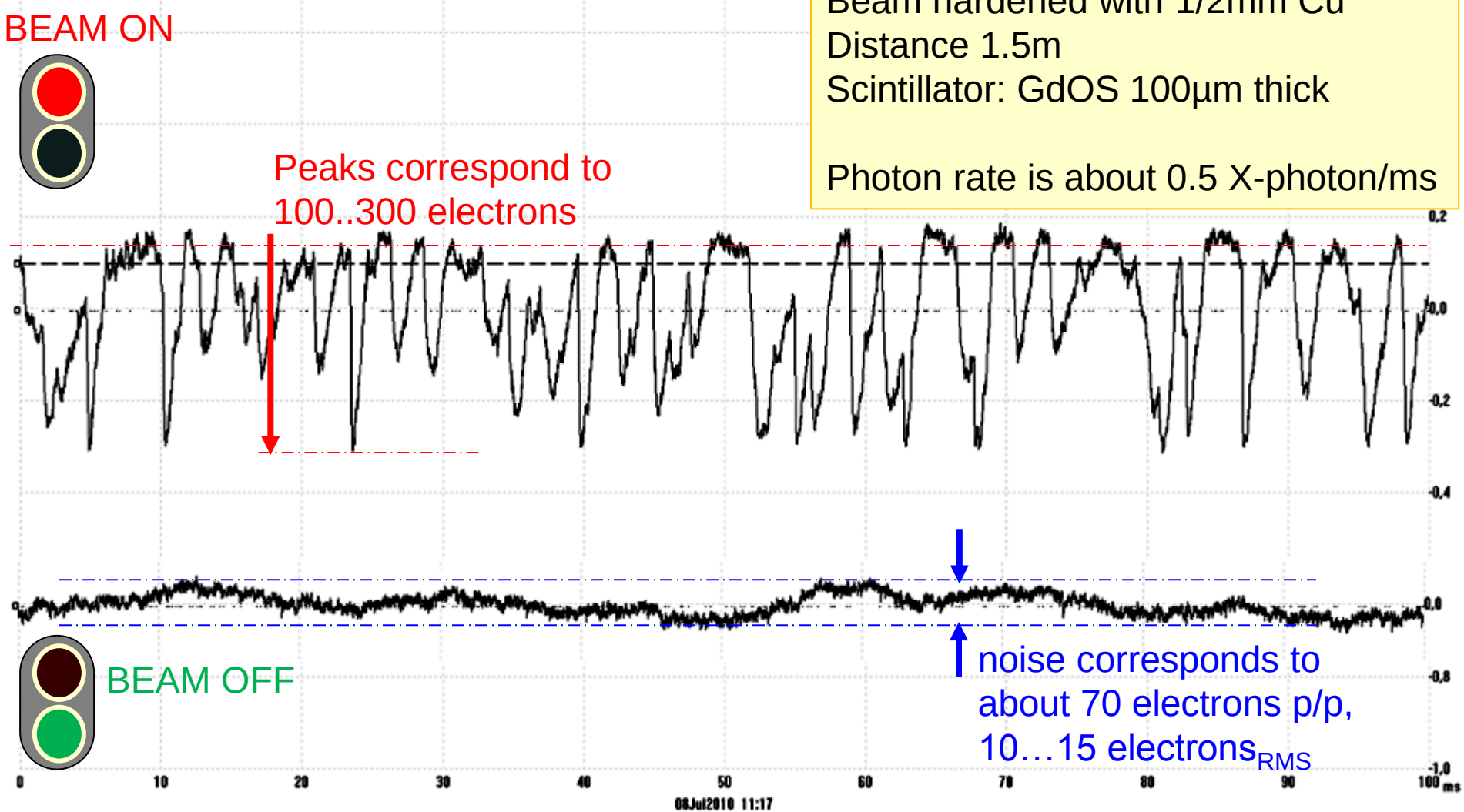
Red: Analog count

- ~40mV/count

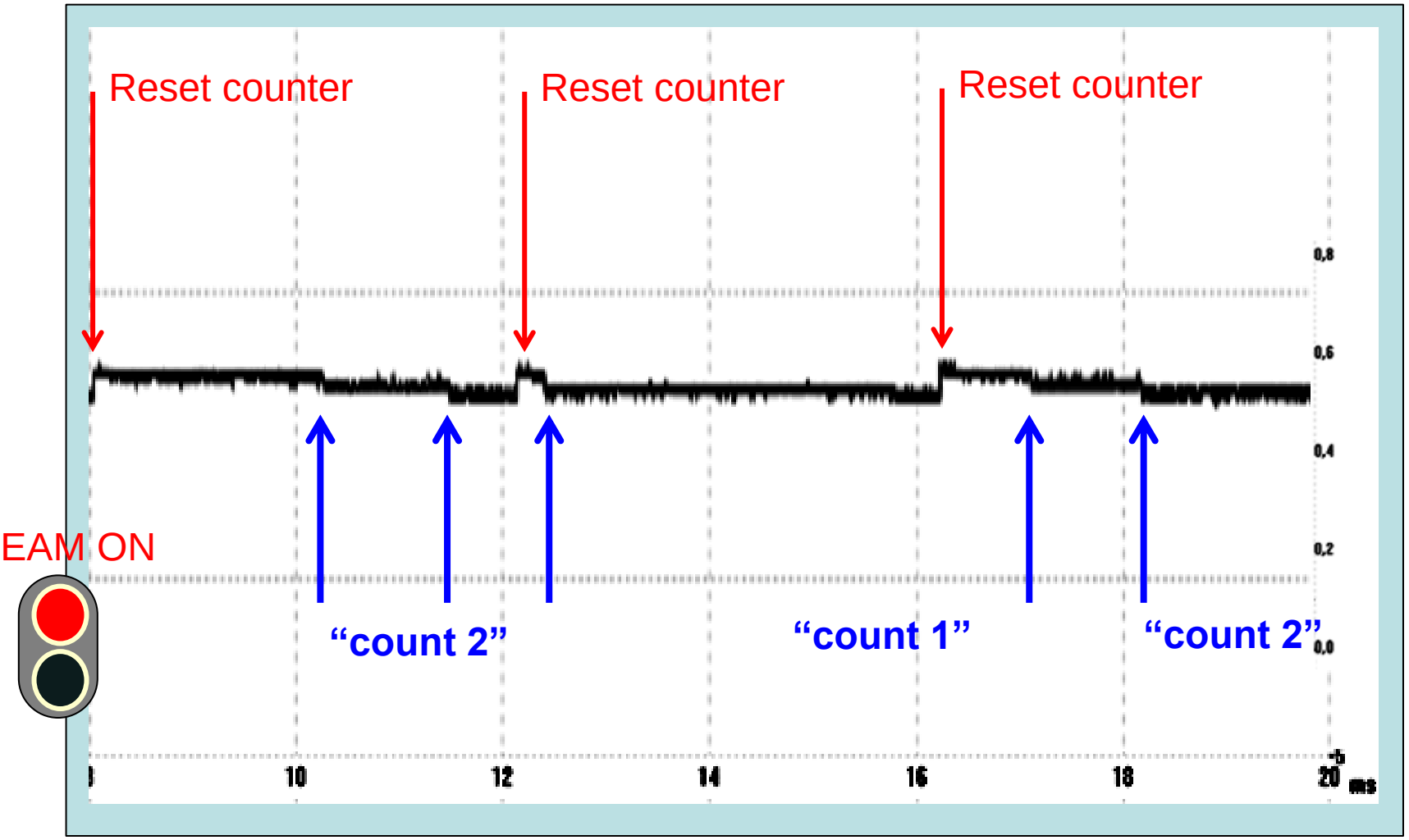
X-ray illumination: comparators's real time signal

X-ray source: 70kVp, 1mA
Beam hardened with 1/2mm Cu
Distance 1.5m
Scintillator: GdOS 100µm thick

Photon rate is about 0.5 X-photon/ms



X-ray illumination: pixel's analog count



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Conclusions

Indirect X-ray photon counting demonstrated

- Detects and counts charge packets <100e-
- Pixel has only 27 MOSFETs
- Pixel has ~80% fill factor

Future challenges

- Increasing array size
- Improving performance (noise, speed)
- Enhancing functionality (energy discrimination)

Thank you

Acknowledging for the
X-ray experiments