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Indirect X-ray Pixel with High Dynamic Range by using combined counting & integration

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Outline

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- **Purpose**
- **Background: *photon counting X-ray***
- **Proposed pixel topology**
- **Circuit concept and layout**
- **Initial results**
- **Conclusion**

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Chapter 1

PURPOSE

Purpose

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- Illustrate the concept, design and initial measurements of a
- Pixel for indirect X-ray detection
- Providing combined photon counting and charge integration capability

Purpose

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- **We demonstrate the huge dynamic range achievable of 100,000:1 (100dB)**
  - *At low flux:* quantum limited photon counting
  - *At high flux:* saturation only limited by the size of the integrating capacitor

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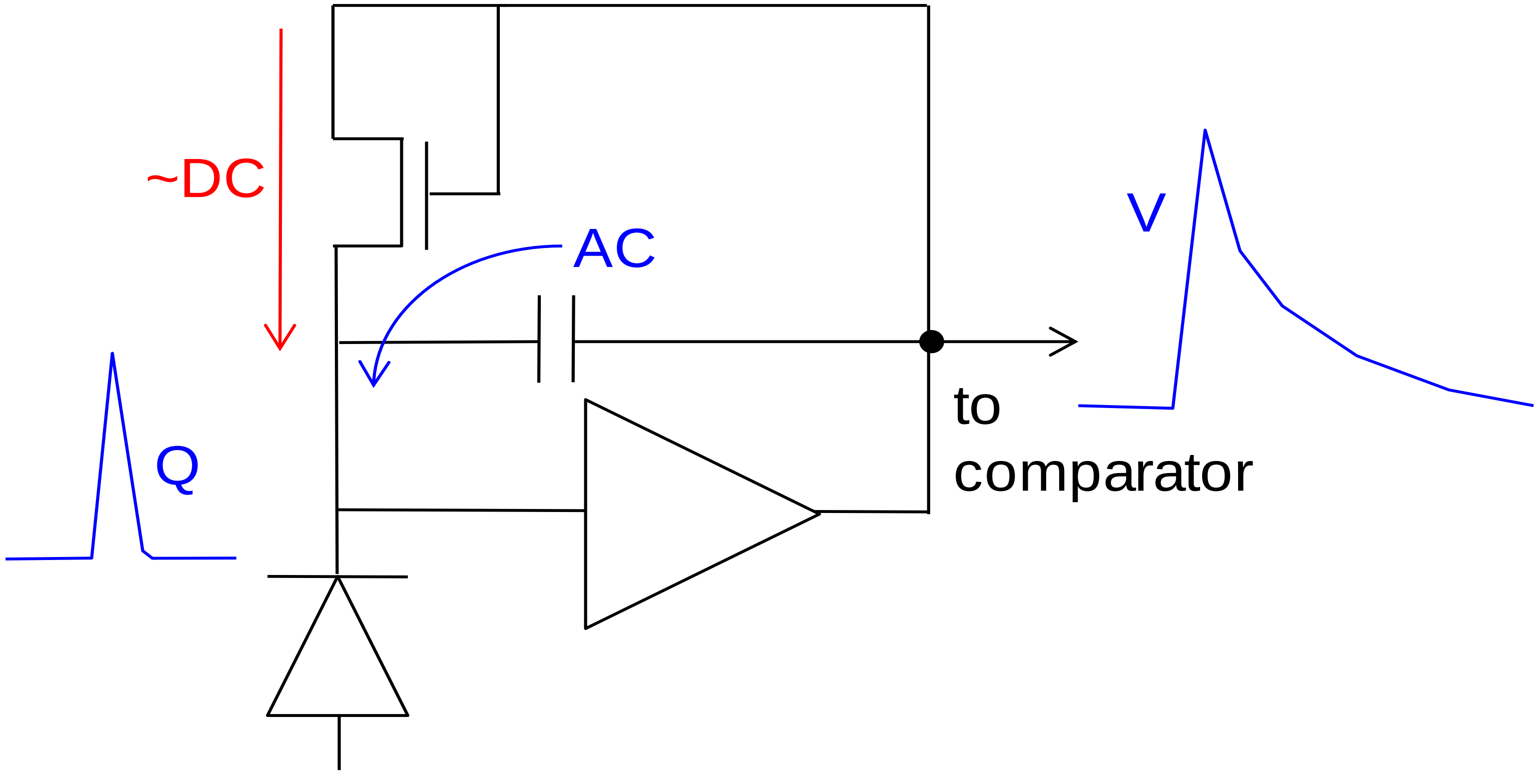
Chapter 2

BACKGROUND:
PHOTON COUNTING X-RAY

Background

- **Caeleste ISSCC 2011:**

First demonstration of indirect X-ray photon counting



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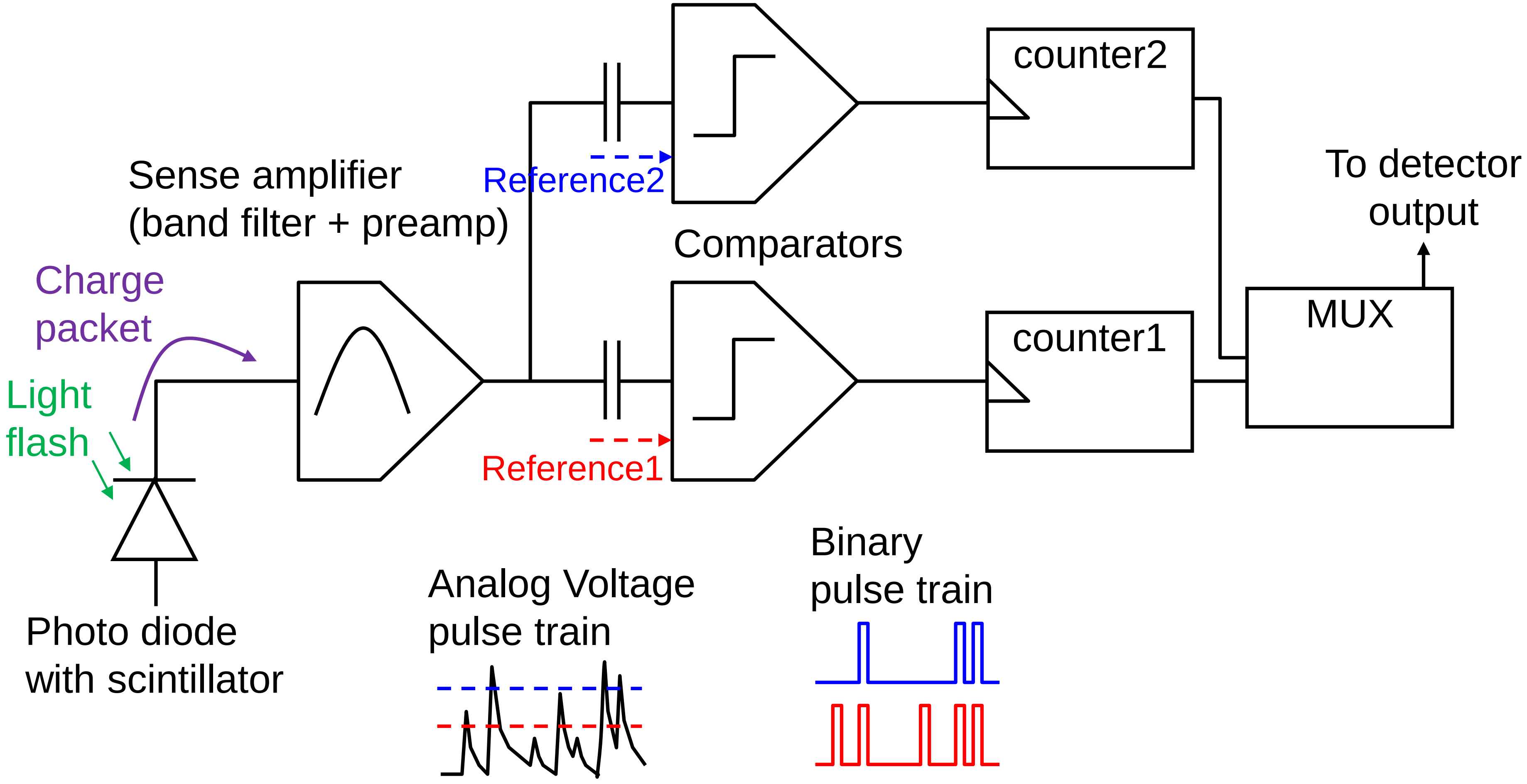
- **X-ray photon counting pixel with two or more energy bands *(IISW 2013)***



Background: *limitations*

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- Count range
  - Limited by size (Silicon area, FF, QE…)
  - Limited by counter type
- Power consumption
  - Count rate, counter paralysis
  - Number of energy channels (“colors”)
- Circuit noise
  - Difficult to detect low energy photons
  - All photons below threshold are not detectable
  - False positives / false negatives

Overcoming the limitations?

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- Count range
  - Limited by size
  - Limited by counter type

Not an issue for charge integrating pixel

- Power consumption
  - Count rate, counter paralysis
  - Number of energy channels

Not an issue for charge integrating pixel

- Circuit noise
  - Difficult to detect low energy photons
  - Lost low-energy photons
  - False positives / negatives

Not an issue for charge integrating pixel

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Chapter 3

PIXEL TOPOLOGY

Pixel topology

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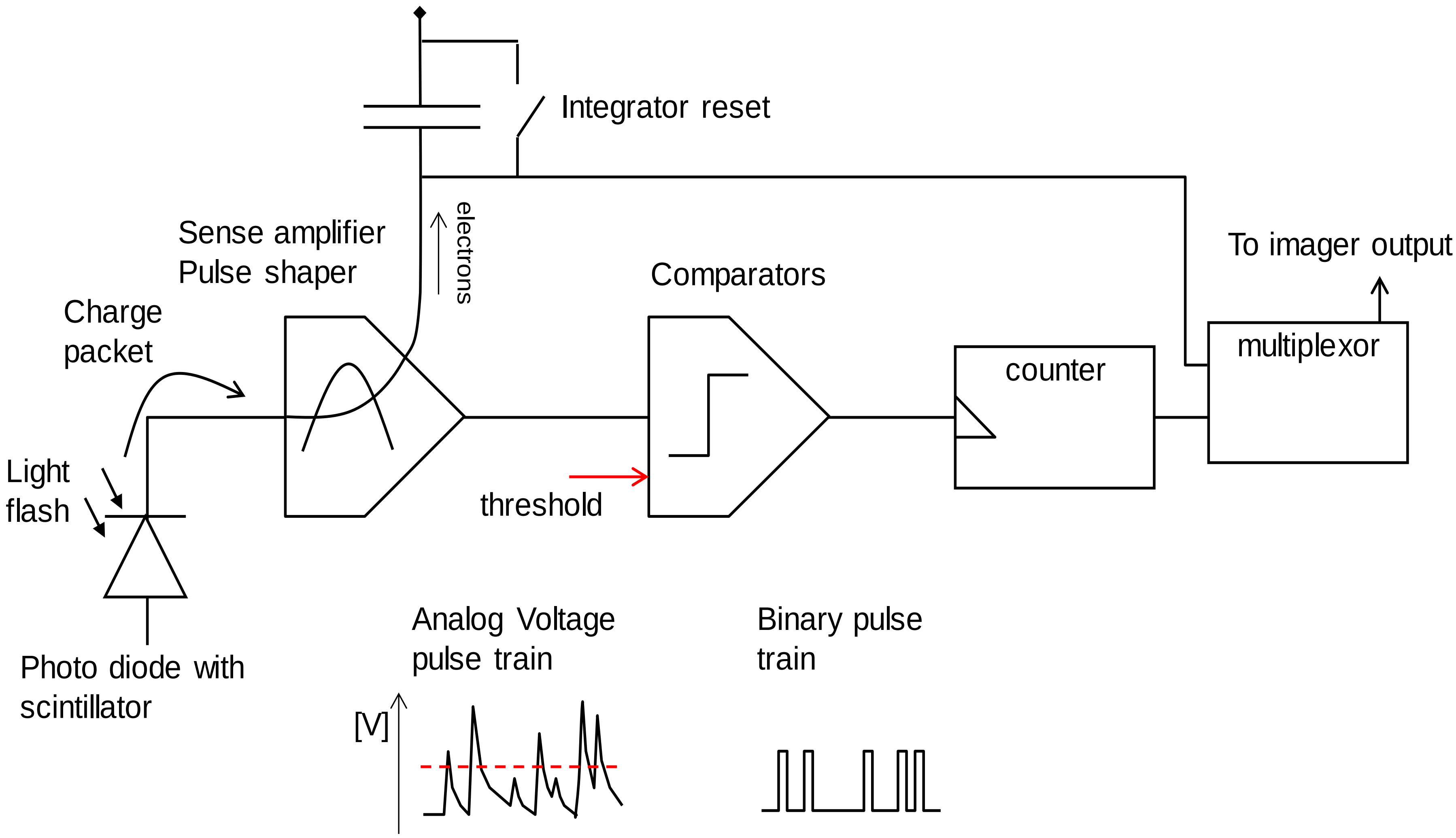
Combined photon counting & charge integration



Pixel topology

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Combined photon counting & charge integration

- The photo-charge packet
  - Triggers the pulse shaper
  - Simultaneously integrated on a capacitor
- All photocurrent is integrated
  - No photon loss
  - Both counted and not counted
- Intrinsic color X-ray
  - Weight of counted photon: 1
  - Weight of integrated photon: $\propto h\nu$

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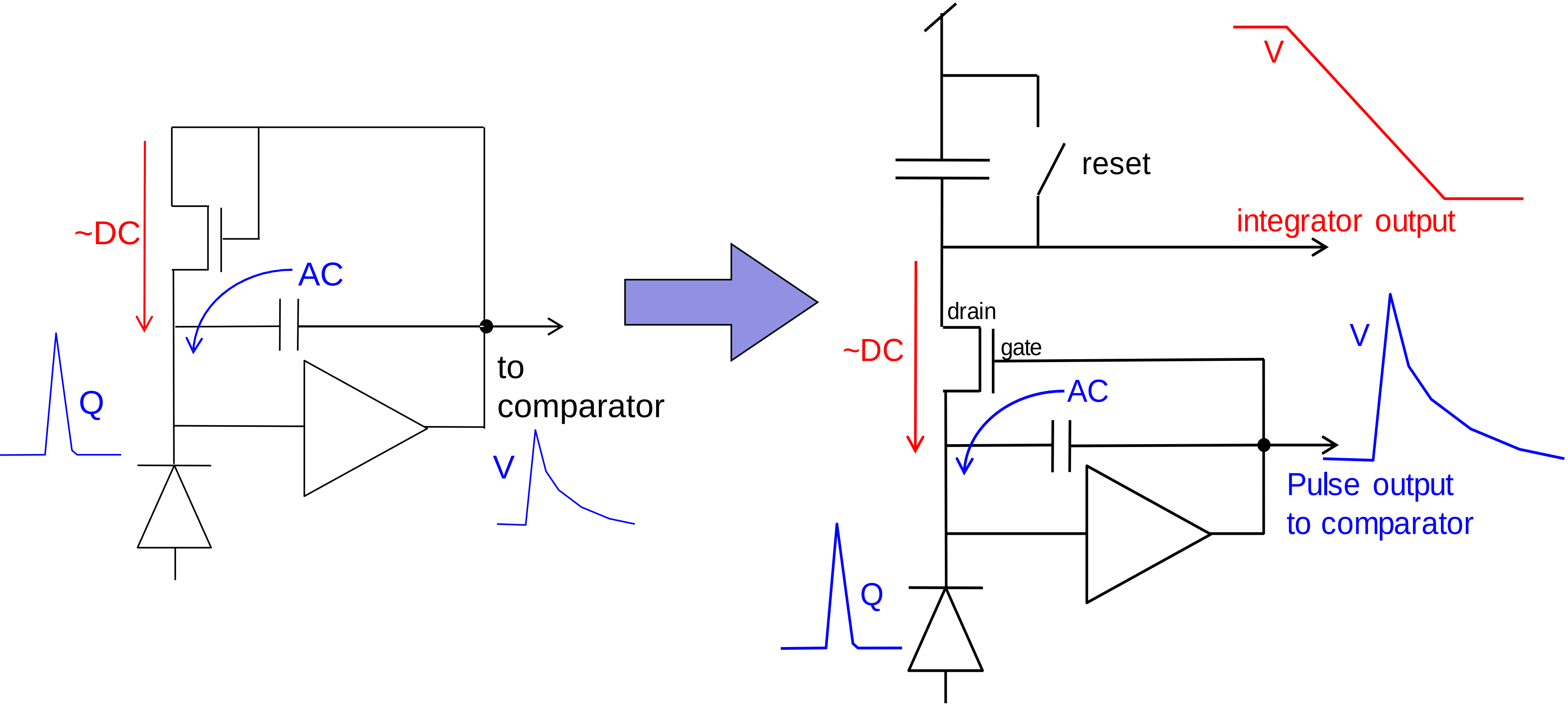
Chapter 4

CIRCUIT DESIGN & LAYOUT

Evolution of concept



Counting only **Counting & Integration**

Evolution of concept

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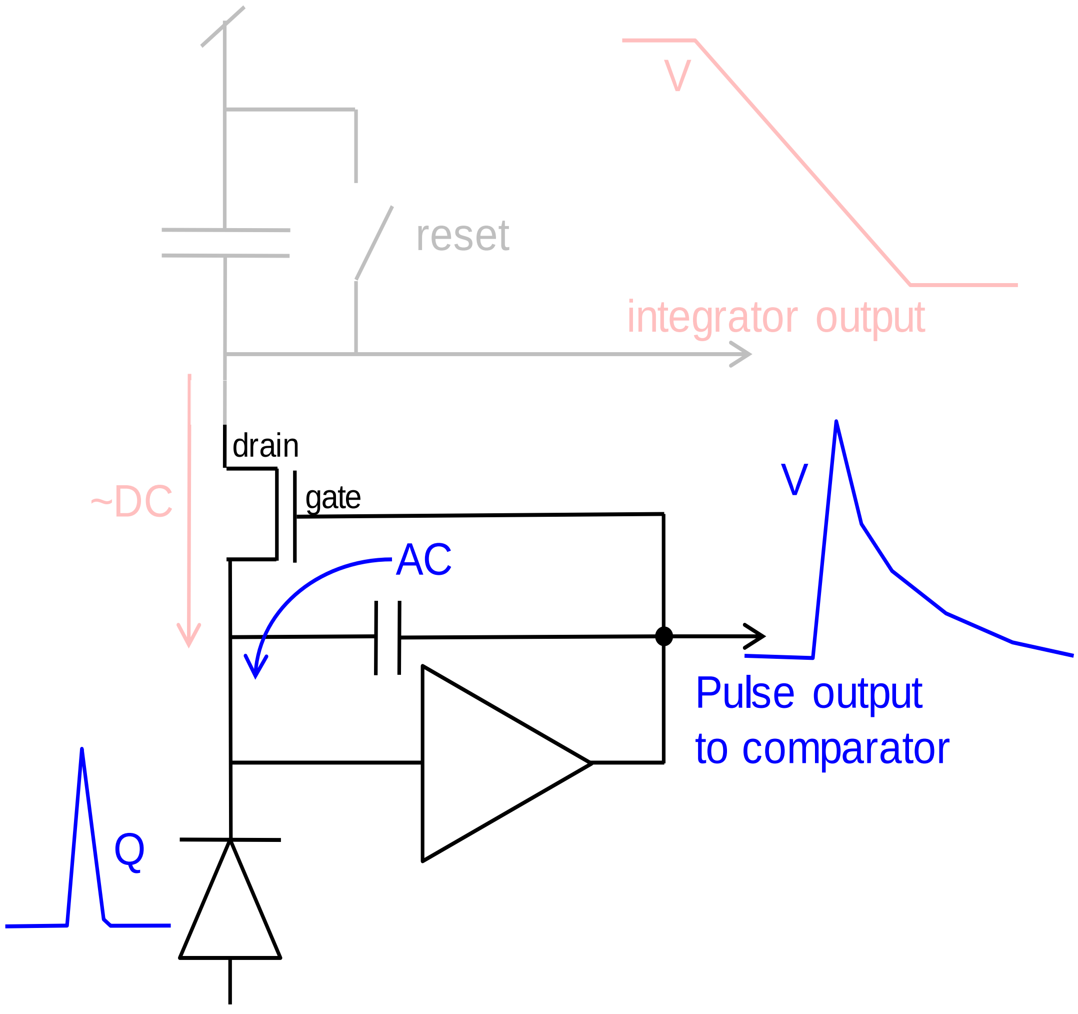
- **Mode of operation: Counting** & Integration



Evolution of concept

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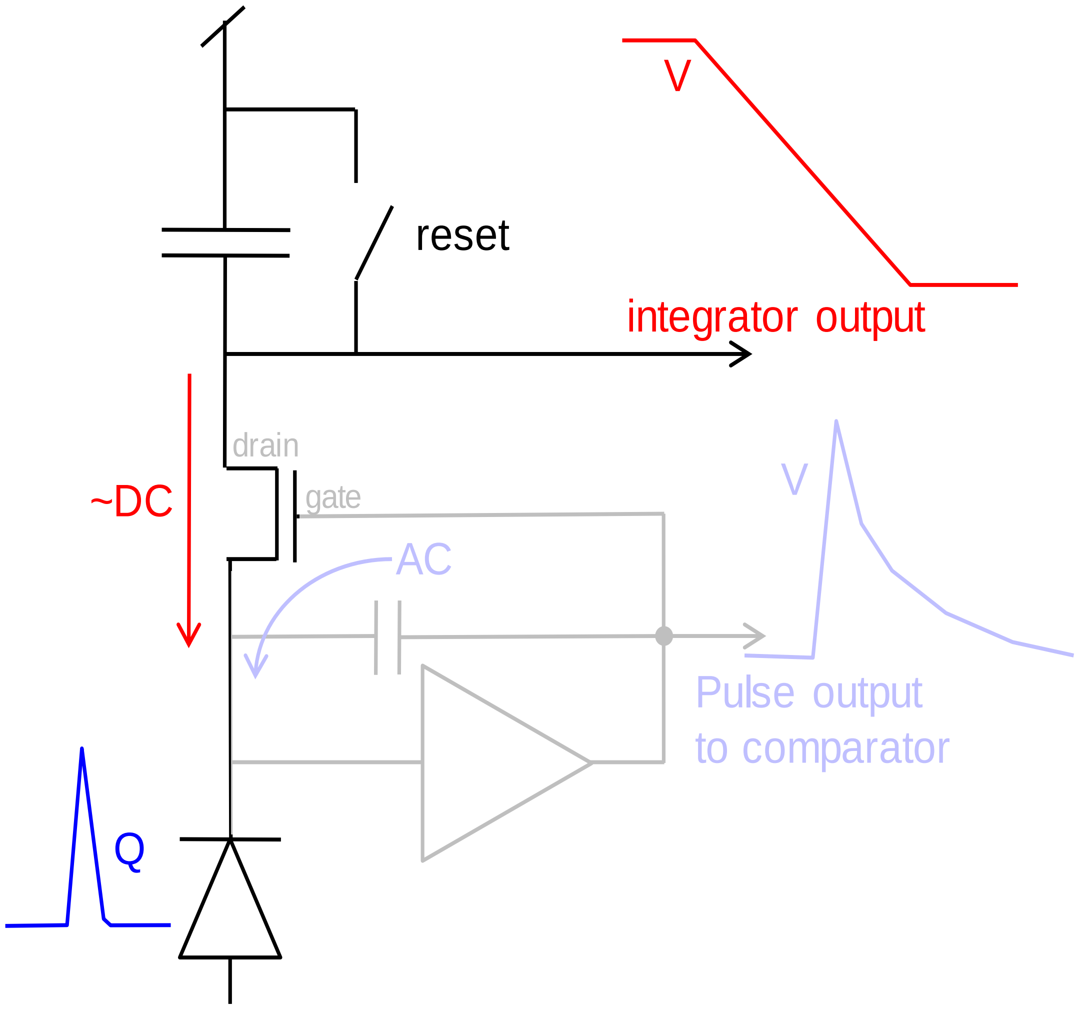
- **Mode of operation: Counting & Integration**



Test pixel layout

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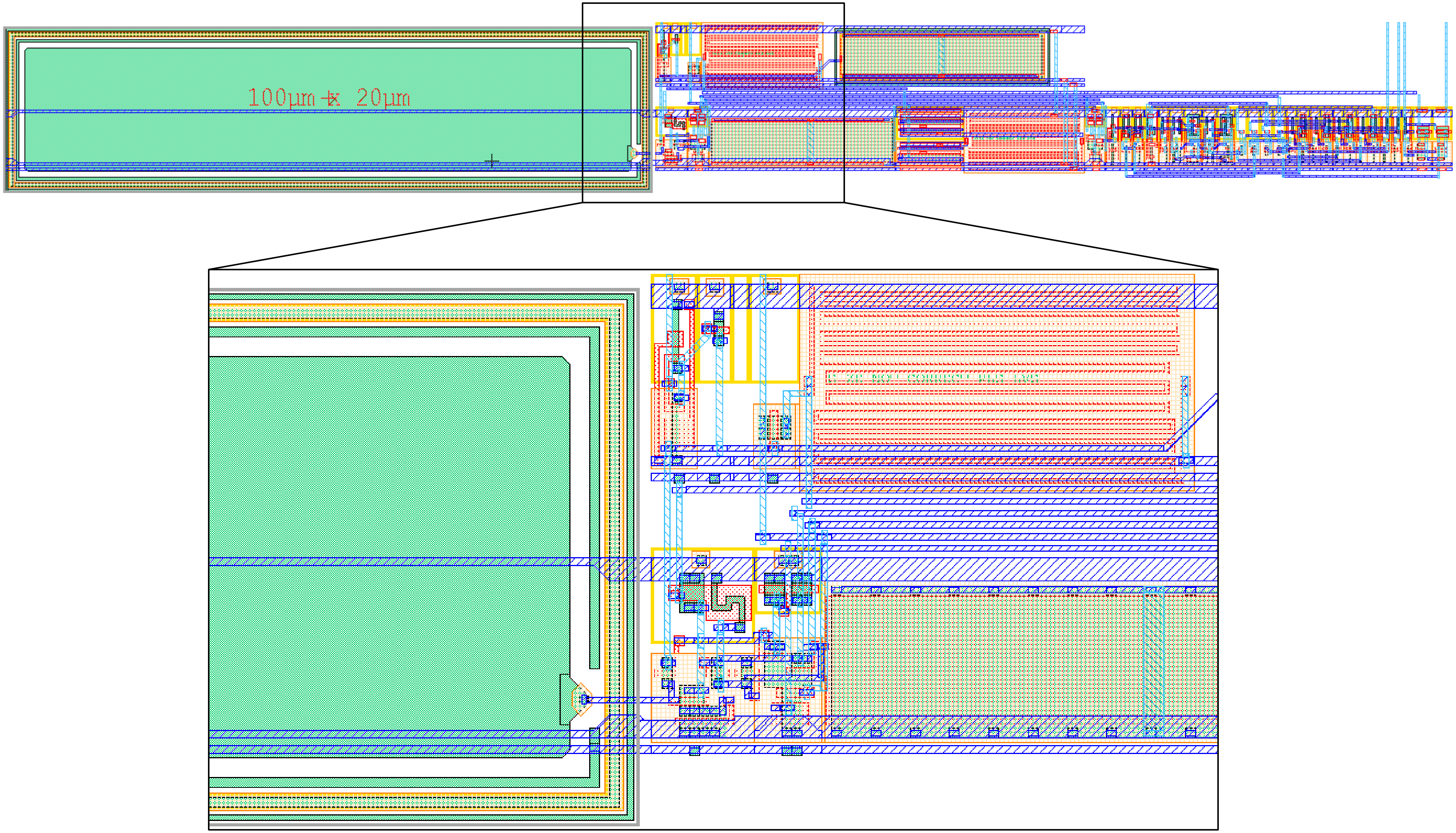

Chapter 5

INITIAL RESULTS FROM THE PROTOTYPE

Prototype device

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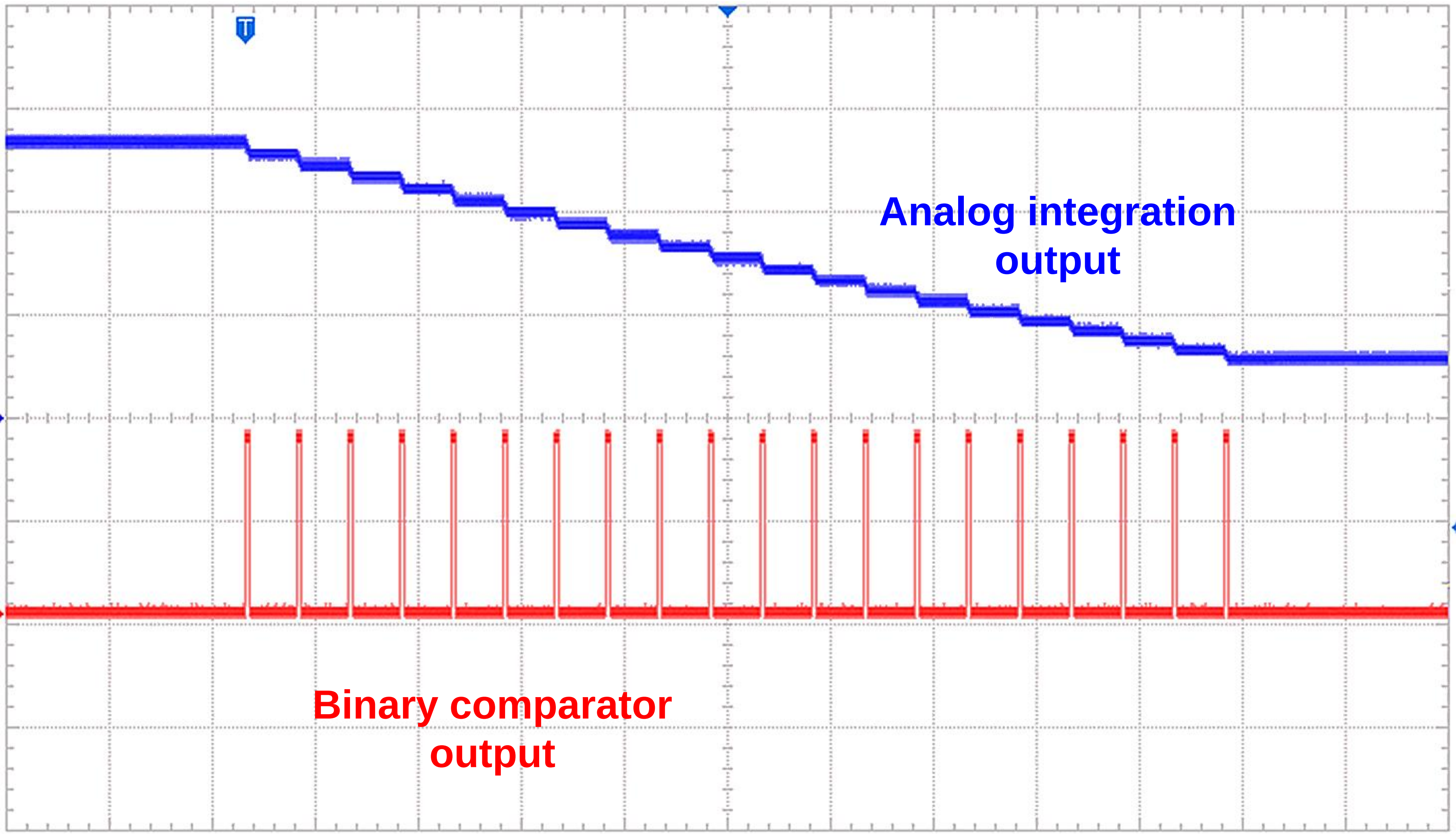
- Single pixel
- XFAB XS018 technology
- Single pinned photodiode 20*100µm
- Pulse shaper with combined integrator
- Analog readout of integrator
- Binary readout of comparator
  (pulse, SR FF or Toggle FF)
- Integration capacitor: 1pF
- Minimum charge packet: ~ 350e^-

All measurements performed using a LED

Response to large LED pulses



Combined Dynamic Range

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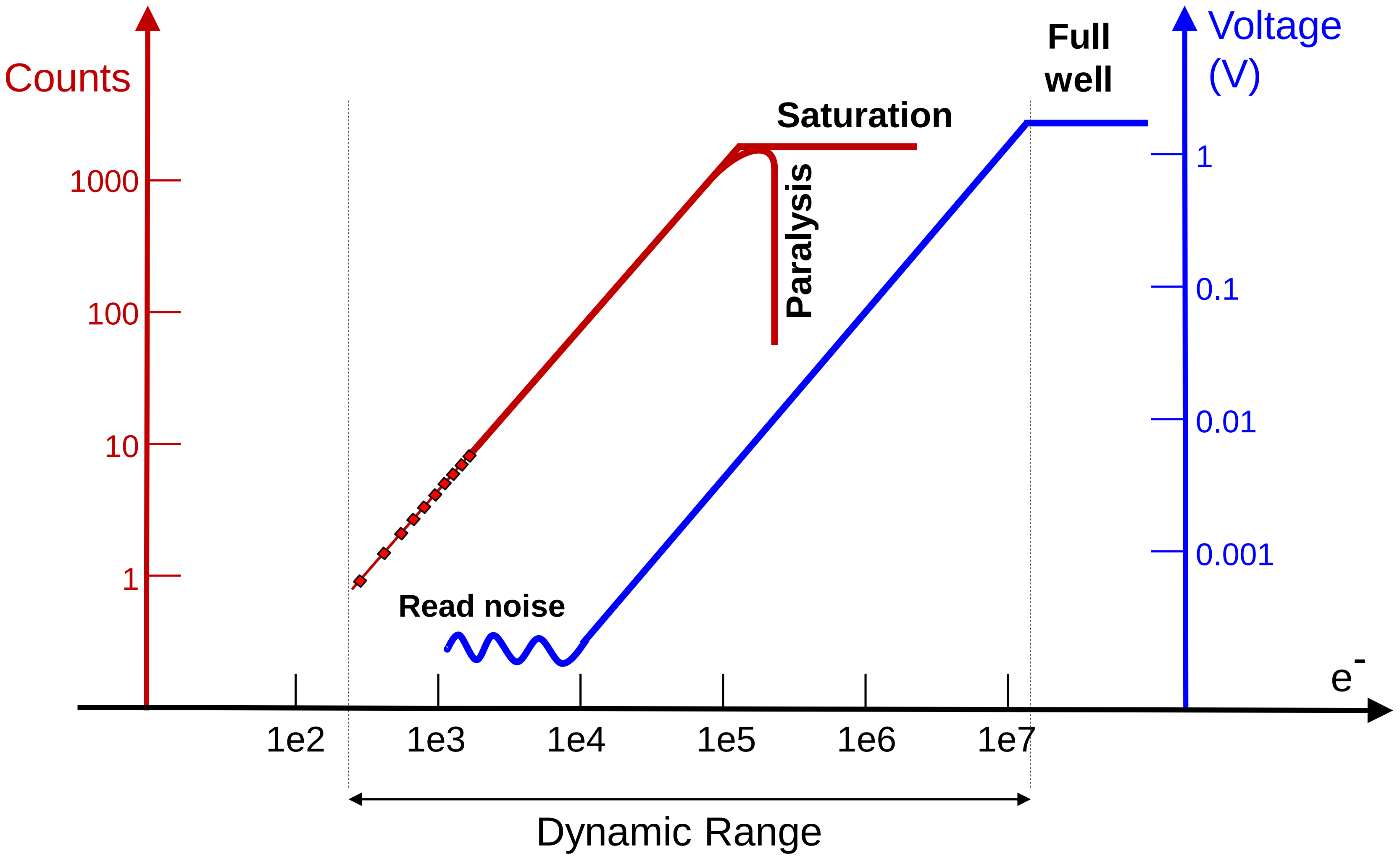

Possible application domains

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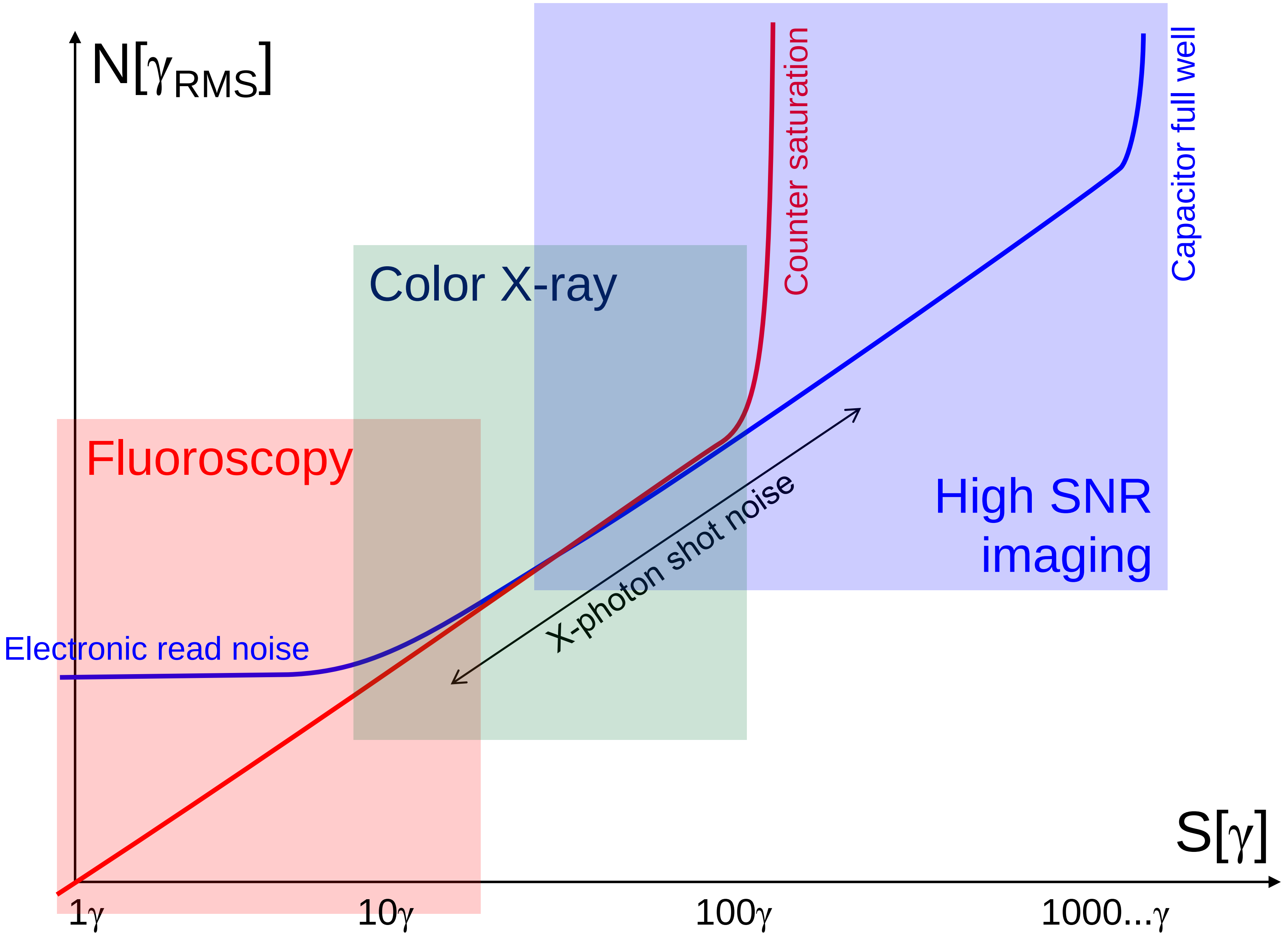

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Chapter 6

CONCLUSIONS

Conclusions

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- **Combination of integration and counting proven**
  - Silicon proven with single pixel & LED
  - Exceptionally large dynamic range (~100dB)
  - Not shown: color X-ray capability

- **Future work**
  - Scintillator & X-ray testing
  - Application in large array

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Thank you for your attention

➢ *References*

- **B.Dierickx, Q.Yao, N.Witvrouwen, D.Uwaerts, S.Vandewiele, P.Gao. "X-Ray Photon Counting and Two-Color X-Ray Imaging Using Indirect Detection." *Sensors* 16, no. 6 (May 26, 2016): 764.**

- **Bart Dierickx, Stijn Vandewiele, Benoit Dupont, Arnaud Defernez, Nick Witvrouwen, Dirk Uwaerts, "Scintillator based color X-ray photon counting imager", IISW, Utah, June 2013**

- **B.Dierickx, S. Vandewiele, B. Dupont, A. Defernez, N. Witvrouwen, D.Uwaerts, "Scintillator based color X-ray photon counting imager", Workshop on medical applications of spectroscopic X-ray detectors, CERN 22-25 April 2013**

- **B.Dierickx, B.Dupont, A.Defernez, N.Ahmed, "Color X-ray photon counting image sensing", IISW, Hakodate Japan, June 2011**

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