Polimi experience towards development of new Front-end solutions for next generation of EuXFEL detectors

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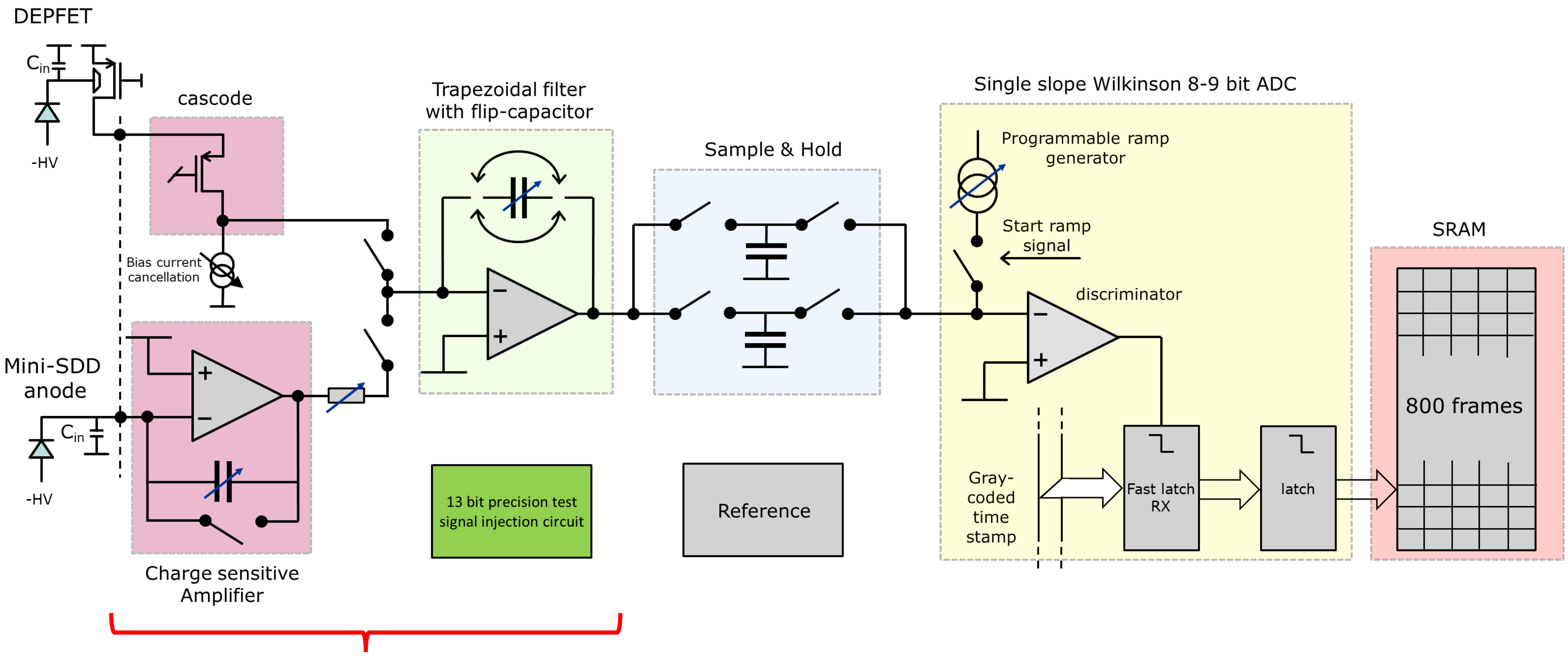
OUTLINE

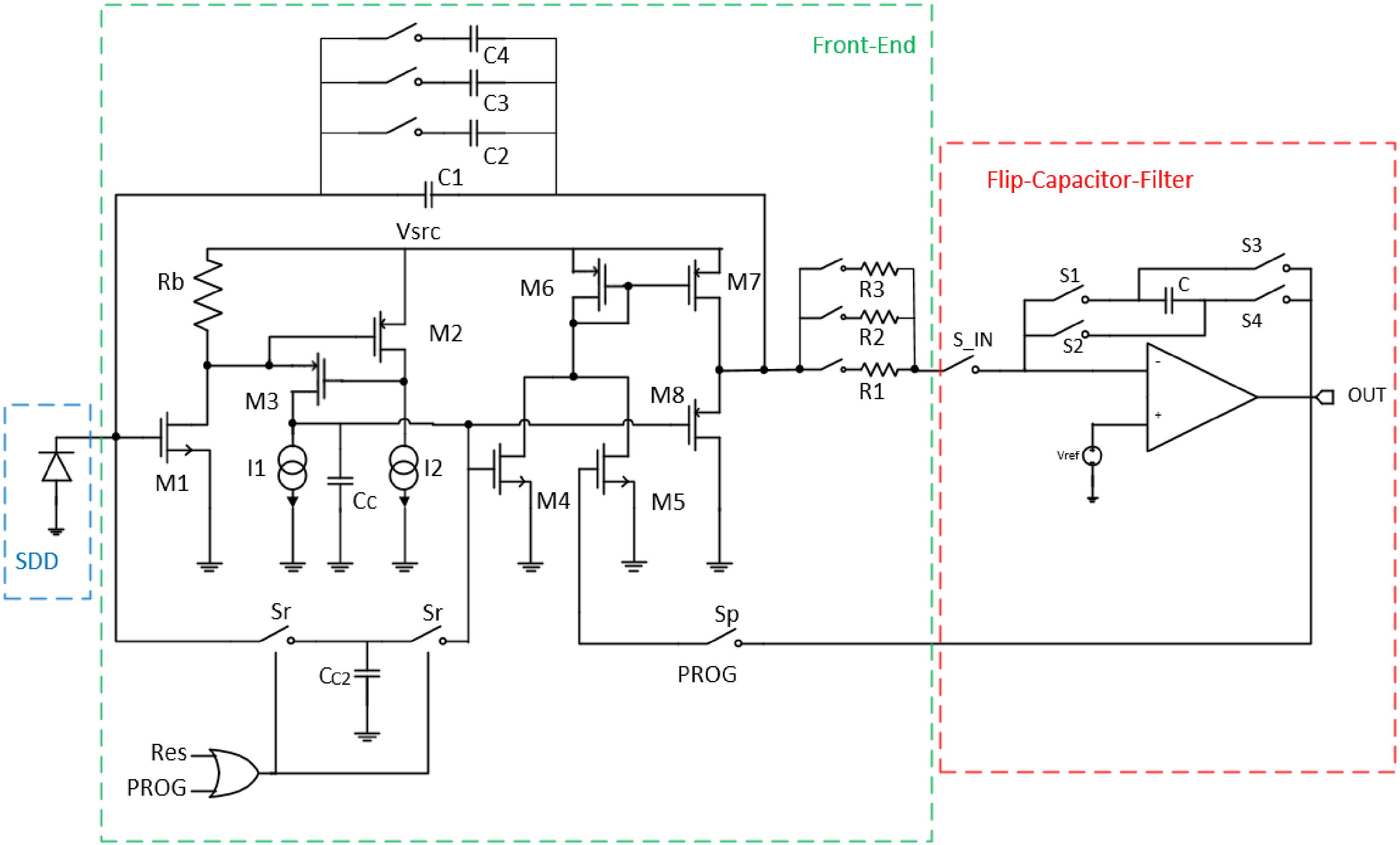
- Front-end design for the DSSC readout ASIC
- Front-end design in 65nm for low noise readout (of UV sensors)
- ‘Predictive’ Gain-Switching approach
- Possible contribution to FE designs for future EuXFEL detectors

The DSSC readout ASIC



POLIMI contributions

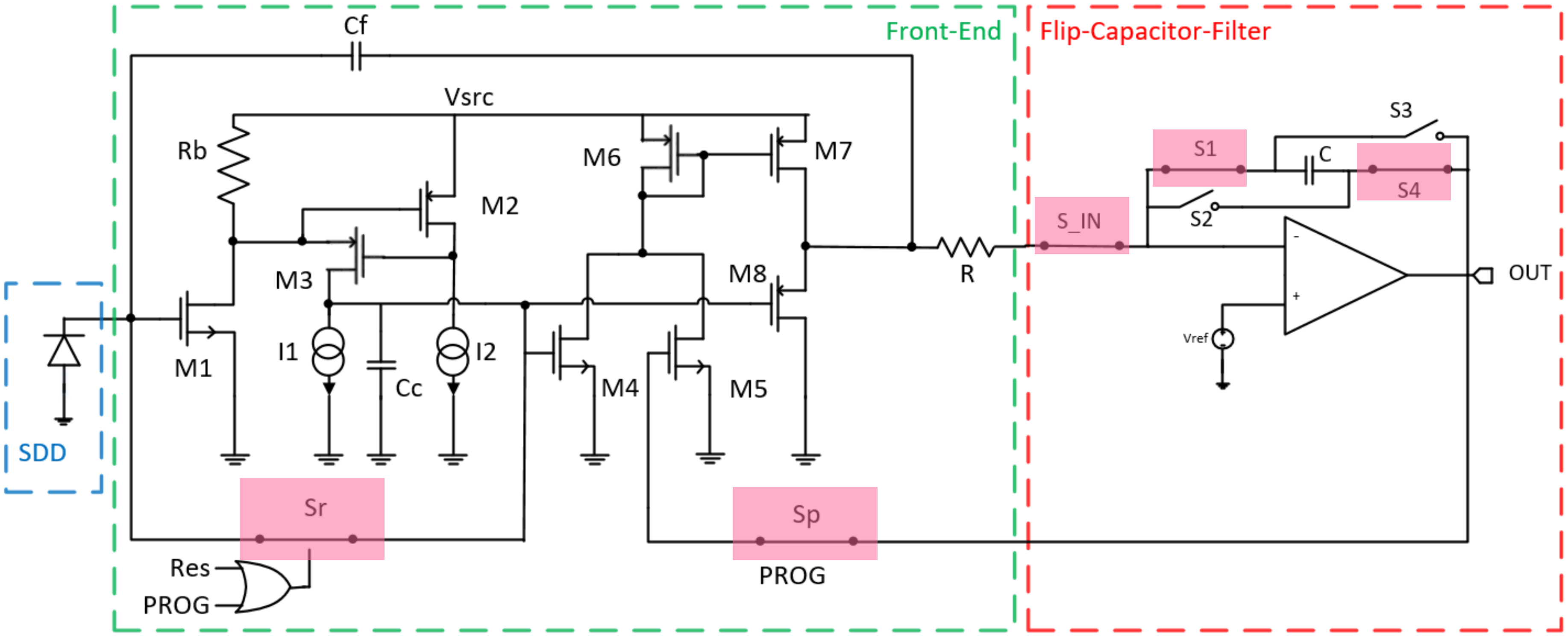
Charge preamplifier for the DSSC readout ASIC (1)



- Selectable feedback capacitor: 60 fF to 360 fF;
- Selectable resistor: 7, 10, 15 kΩ;
- Dynamic range: 256 or 2560 photons;
- Energy range from 0.5 to 3 keV;
- CSA current consumption of 120 μA.

Charge preamplifier for the DSSC readout ASIC (2)

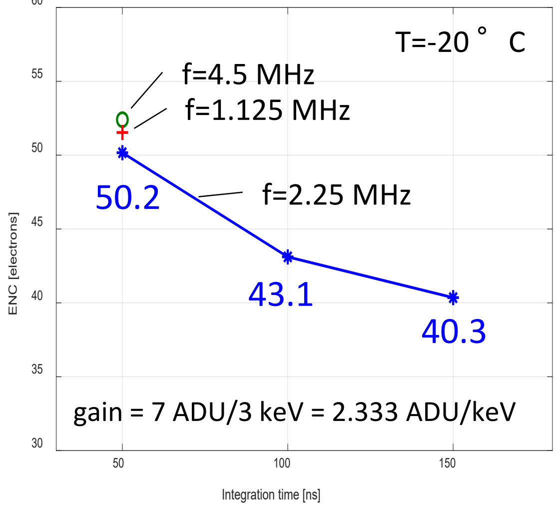
Programming phase



- **A control loop is been implemented during the programming phase**
- **The loop exploits the CSA output stage;**
- **The loop programs the CSA output voltage to the same Filter virtual ground voltage (Offset Compensation).**

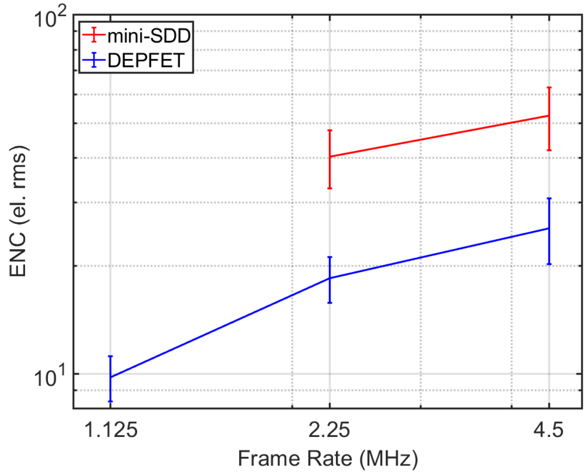
Electronics noise vs. Integration time (courtesy M.Porro)

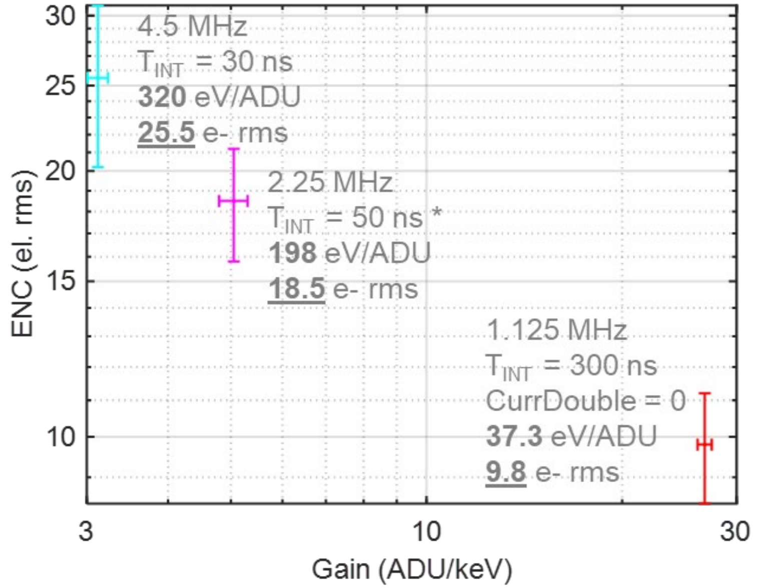
Noise vs. T int @ 2.25 MHz



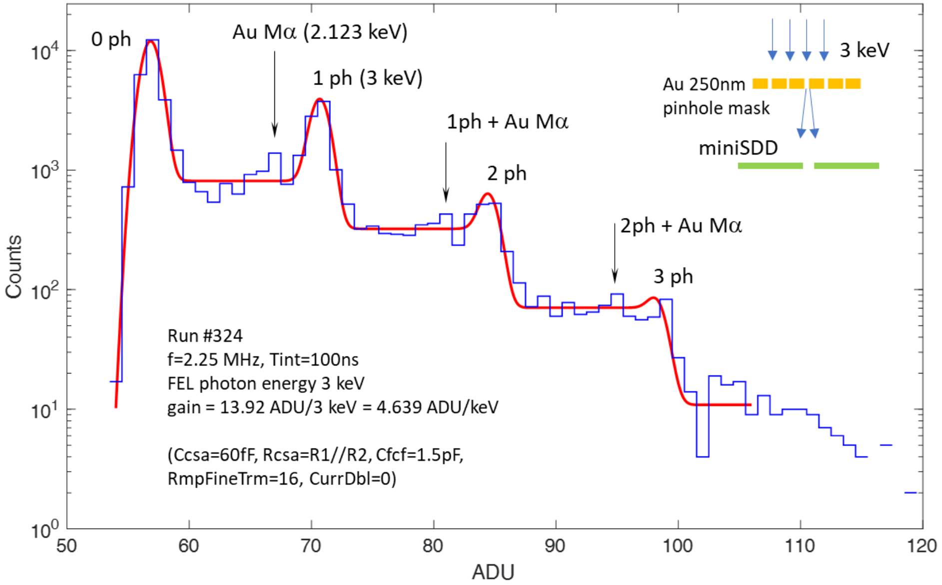
Mini-SDD Front-end

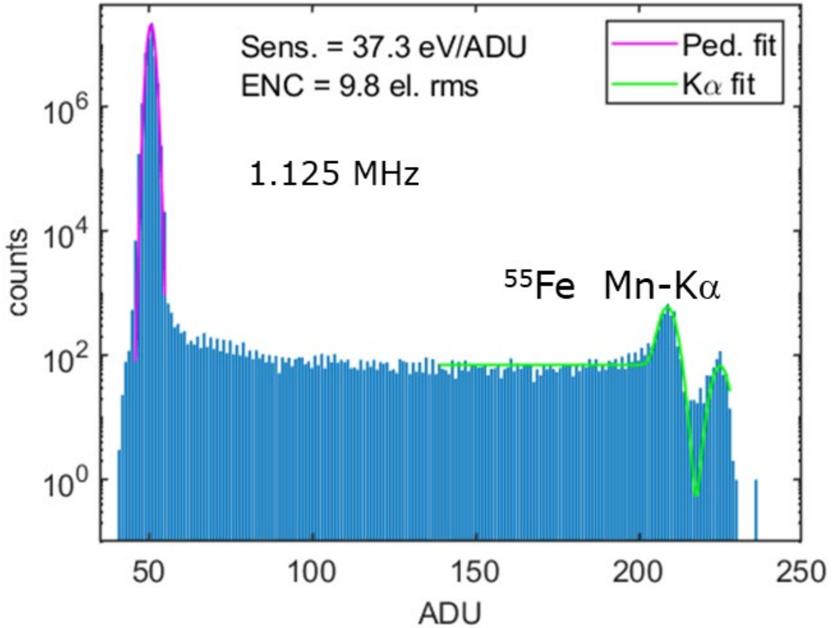
DEPFET Front-end



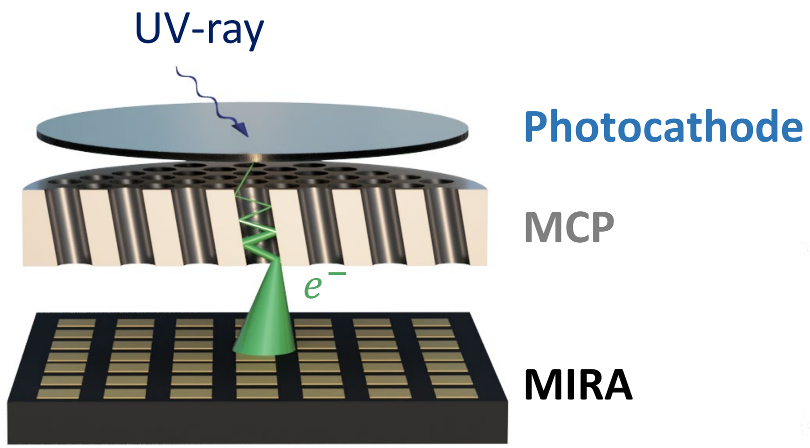


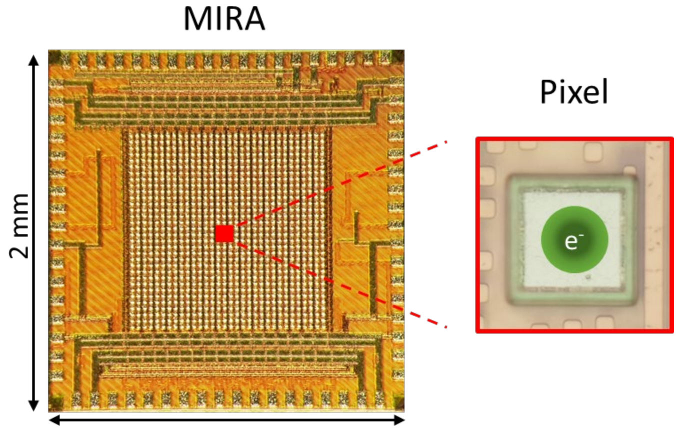
Spectral resolution @ 3keV + Au Mα (2.123keV)

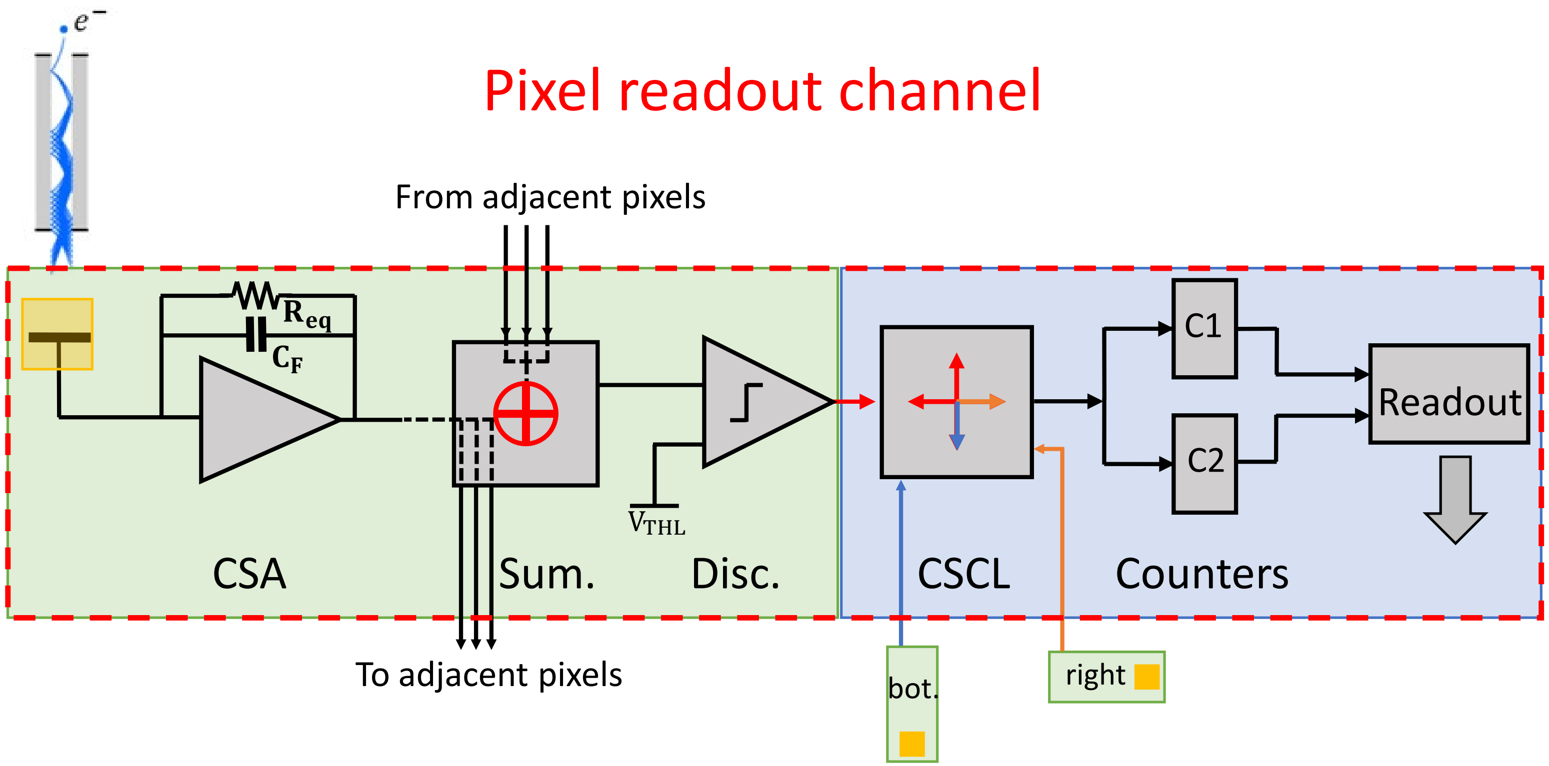




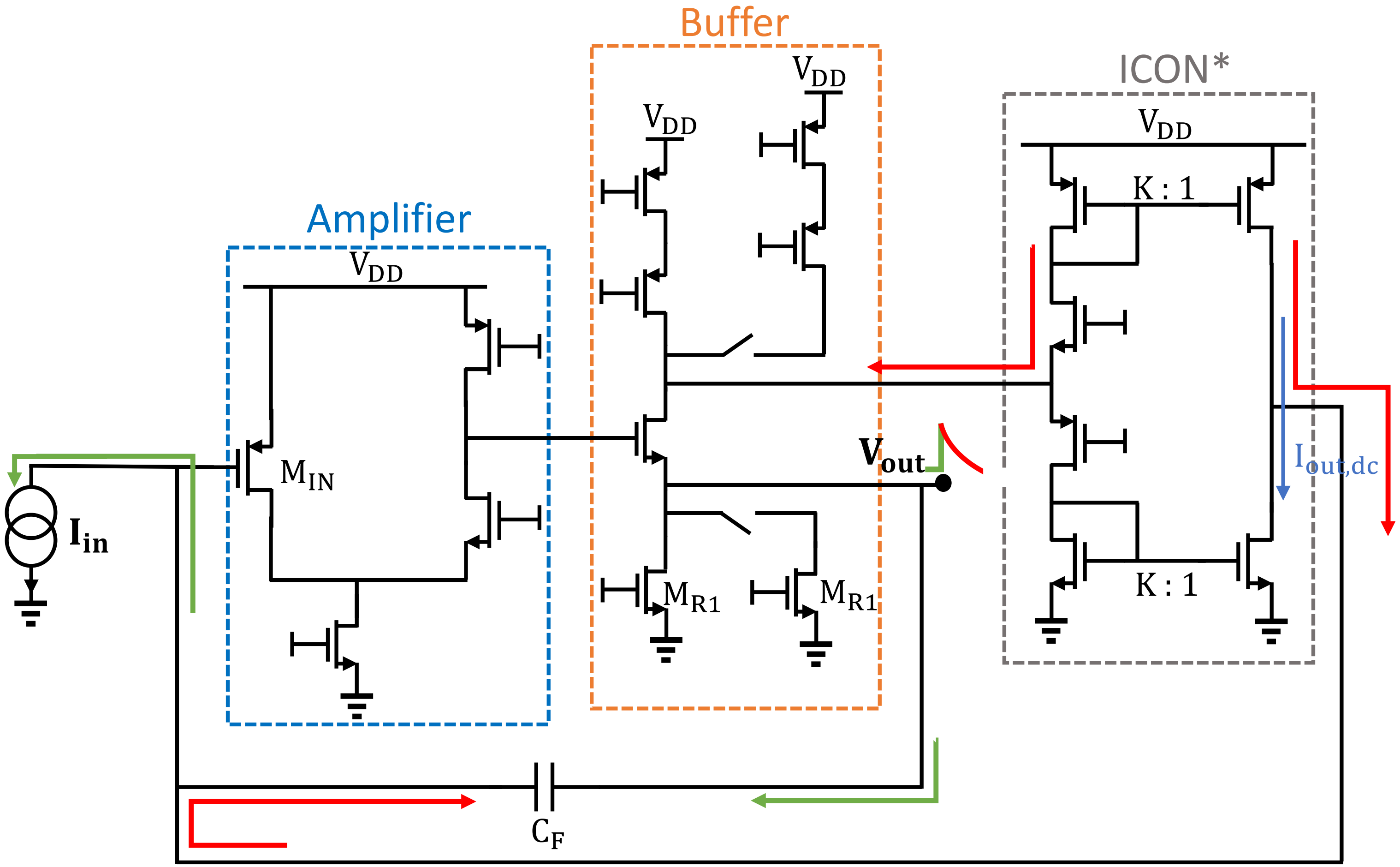
Pixel Readout in 65nm (MIRA ASIC)





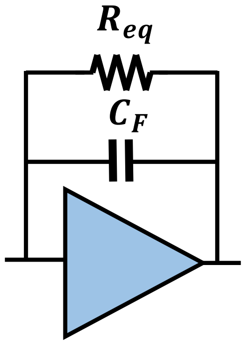


MIRA Charge Sensitive Amplifier (CSA)



MIRA CSA:

- **Folded Cascode Amplifier**
- **Buffer** → Selectable R_1 for different shaping times: **Fast & Slow Mode**
- **ICON*** → Large feedback resistance $\mathbf{R_{eq} = R_1(1 + K)}$ for C_F discharge

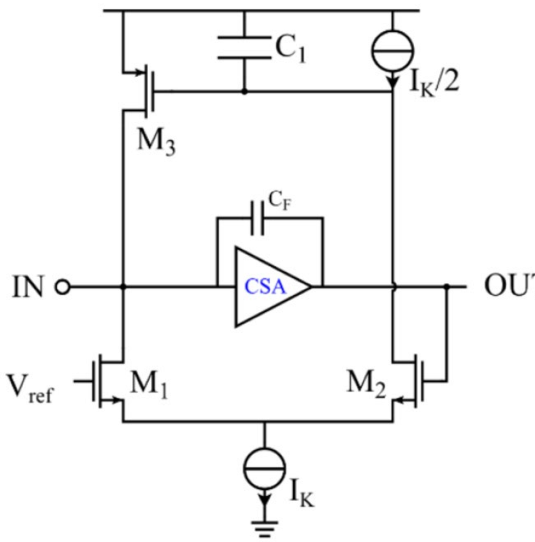


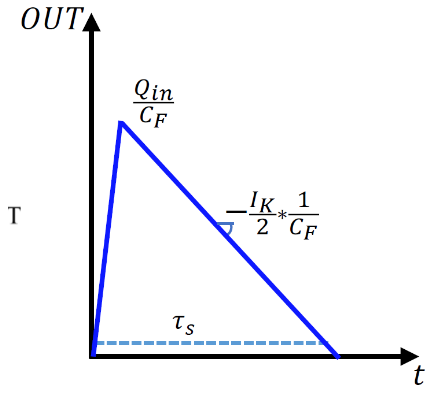
* Refs:

- R. L. Chase, A. Hrisoho, J.-P. Richer: "8-channel CMOS preamplifier and shaper with adjustable peaking time and automatic pole-zero cancellation." Nucl. Instr. and Meth. A, vol. 409, 1998, p. 328–331.
- C. Fiorini and M. Porro, "Integrated RC cell for time-invariant shaping amplifiers", IEEE Trans. Nucl. Sci., Vol. 51, n°5, pp. 1953 –1960, Oct 2004.

Noise current source vs. pulse duration

Krummenacher*

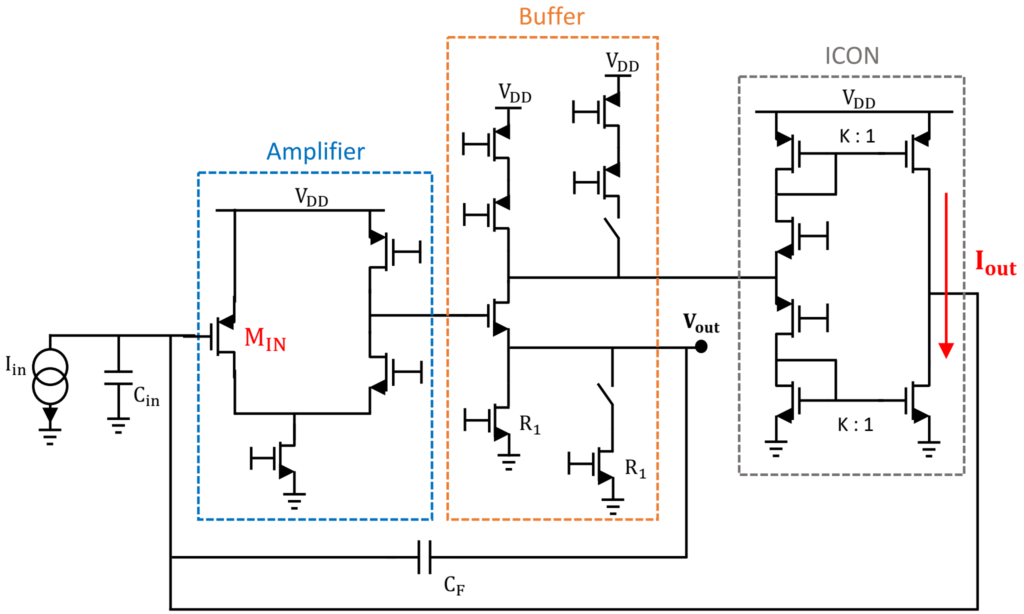




- **Shaping time** $\tau_s \propto \frac{1}{I_K}$
- **Noise current source** $\propto I_K$
- **Dependence** between noise of I_K and shaping time

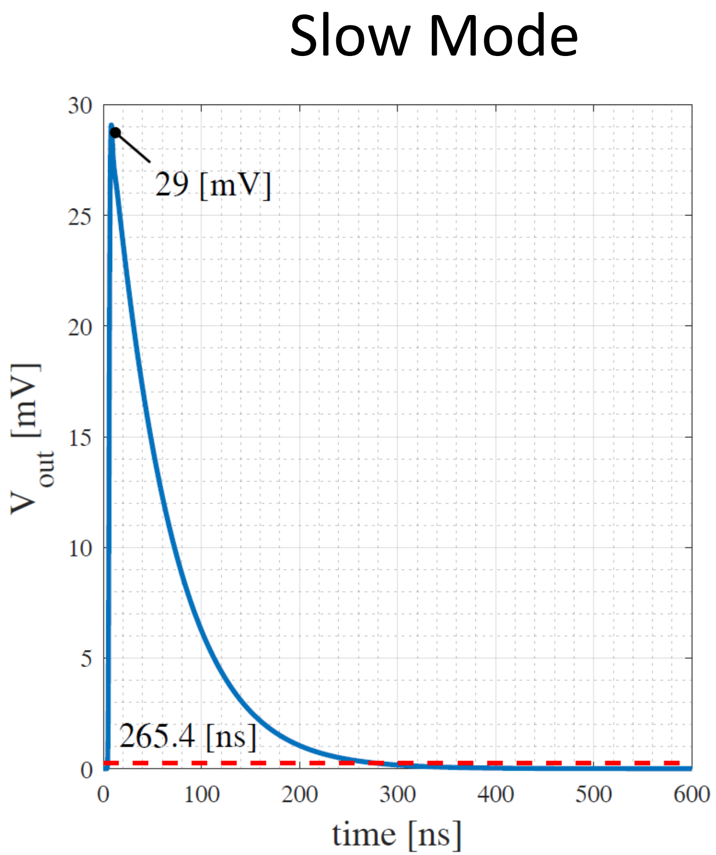
*Ref: Krummenacher, Francois. "Pixel detectors with local intelligence: an IC designer point of view." Nuclear Instruments and Methods in Physics Research Section A **305.3** (1991): 527-532

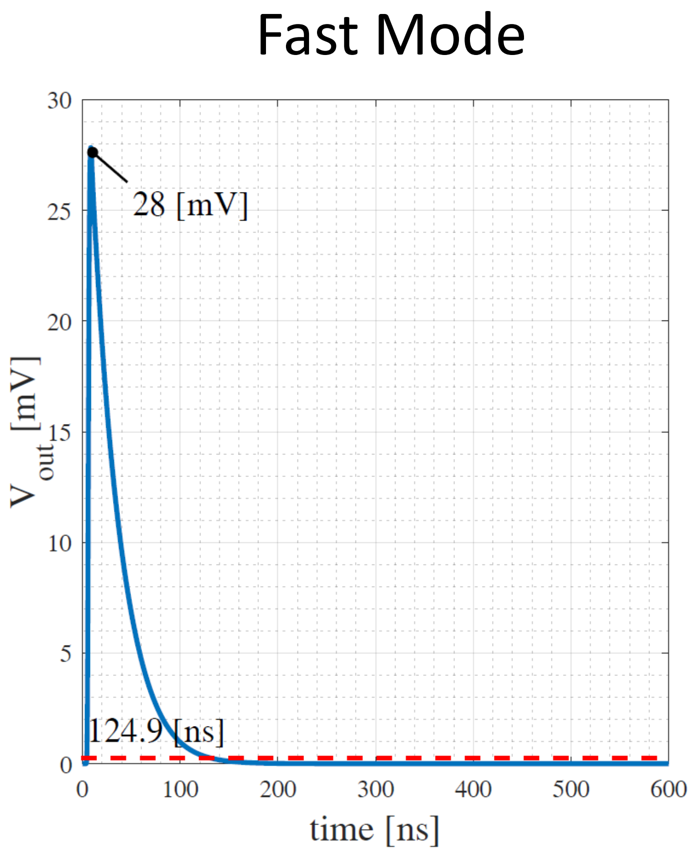
MIRA CSA



- Main **noise current source at the input** $\propto I_{out}$
- **Shaping time** $\tau_s \propto KR_1C_f$
- **No dependence** between noise of I_{out} and shaping time
- Buffer and left-brench ICON noise sources demagnified by a factor K^2 → **negligible**

MIRA CSA Transient Pulse and Noise - Simulations





$\mathbf{Q_{in,MAX}} = 4000\ e^-$

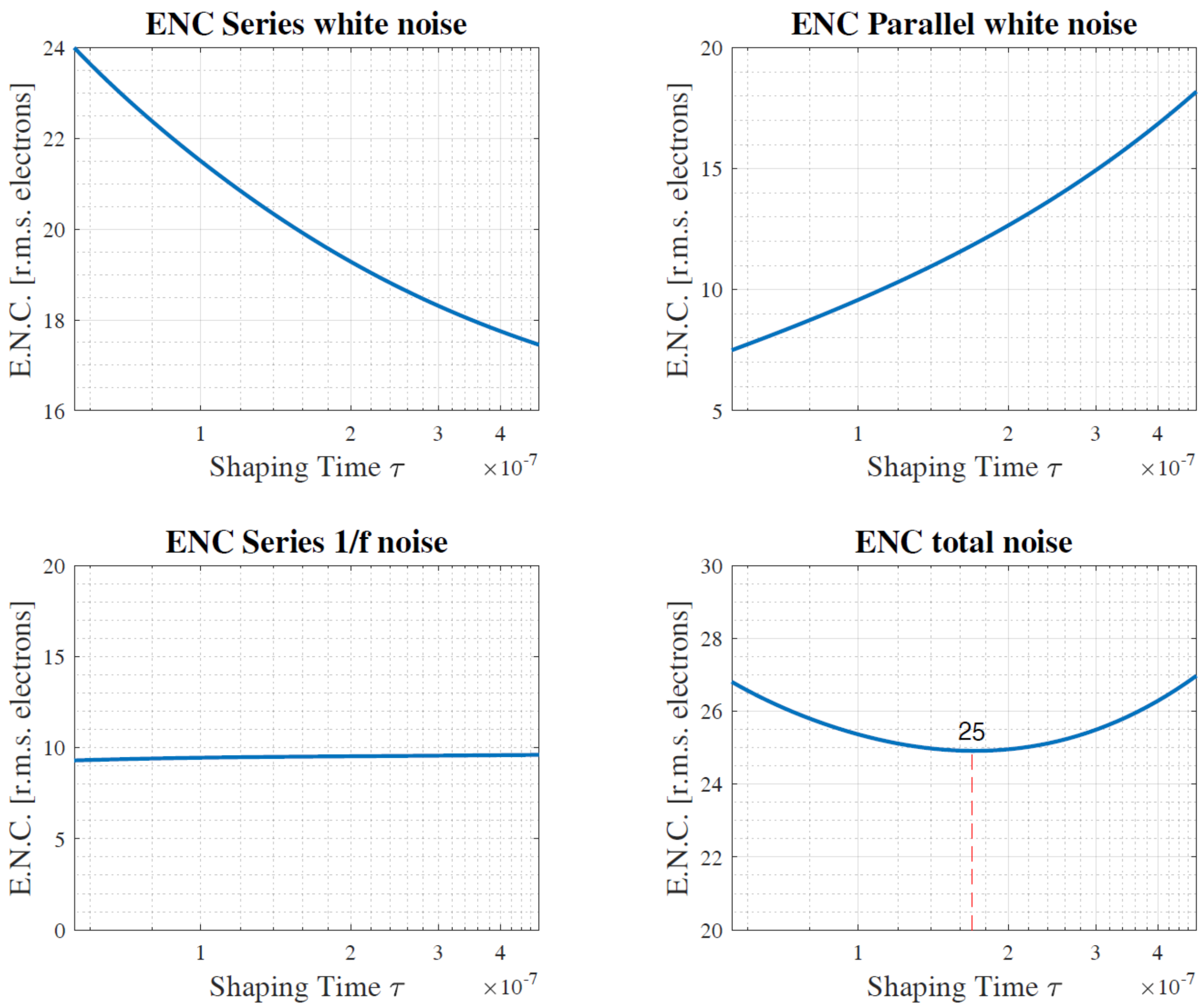
Slow Mode:

- $\mathbf{t_{width}}|_{\mathbf{1\%peak}} = 265$ ns
- $V_{peak} = 29$ mV
- $\mathbf{Q_{in}} = 1000\ e^-$
- $\sigma_{n,vout} = 835\mu V_{rms}$
- $\mathbf{ENC_{CSA}} = 27\ e^-_{rms}$

Fast Mode:

- $\mathbf{t_{width}}|_{\mathbf{1\%peak}} = 125$ns
- $V_{peak} = 28$ mV
- $\mathbf{Q_{in}} = 1000\ e^-$
- $\sigma_{n,vout} = 835\mu V_{rms}$
- $\mathbf{ENC_{CSA}} = 27\ e^-_{rms}$

Noise contributions - Simulations



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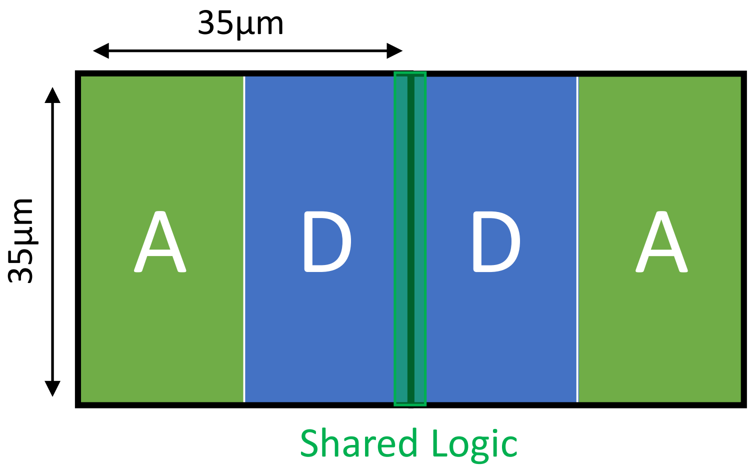
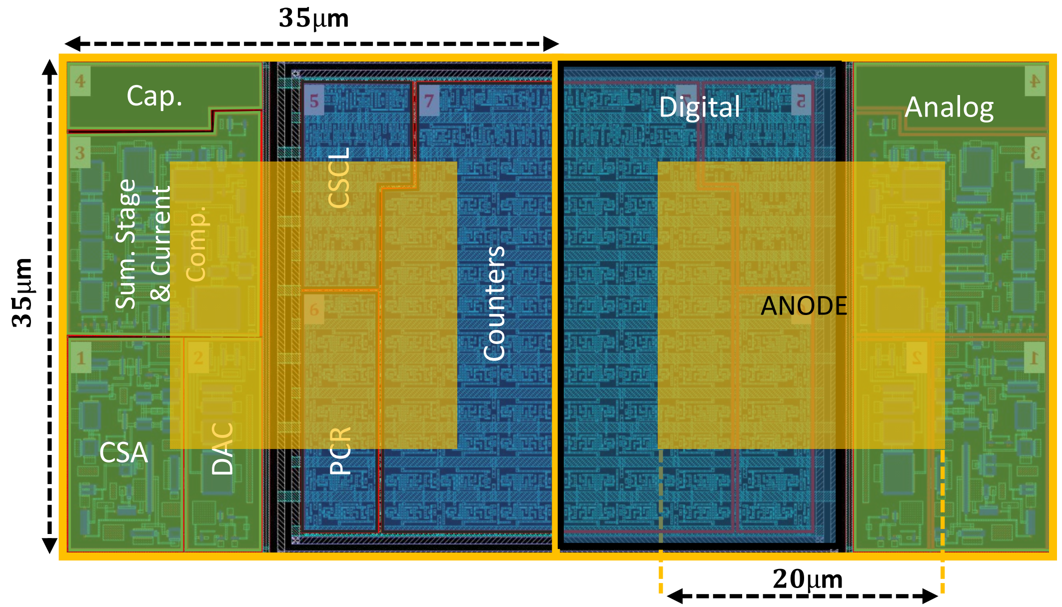
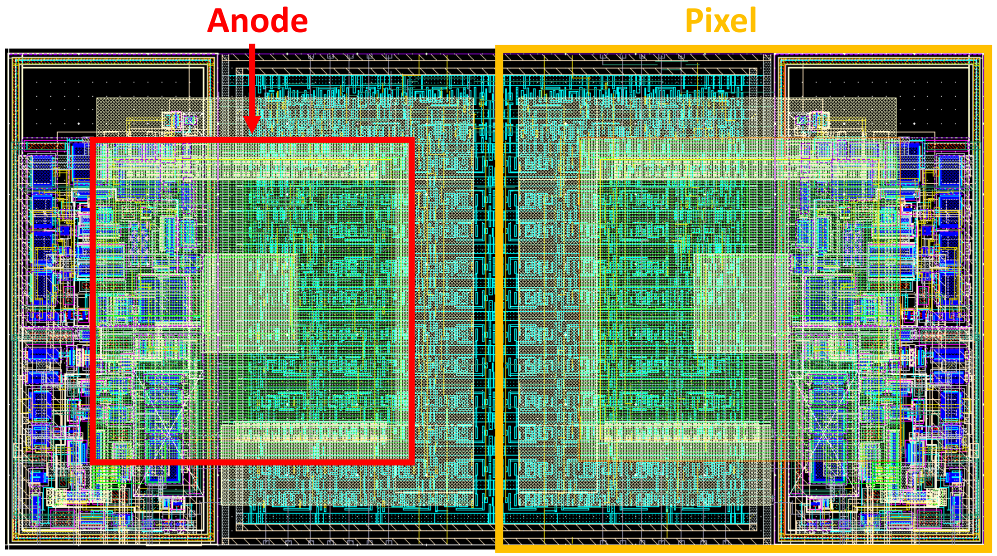
The SuperPixel - Layout



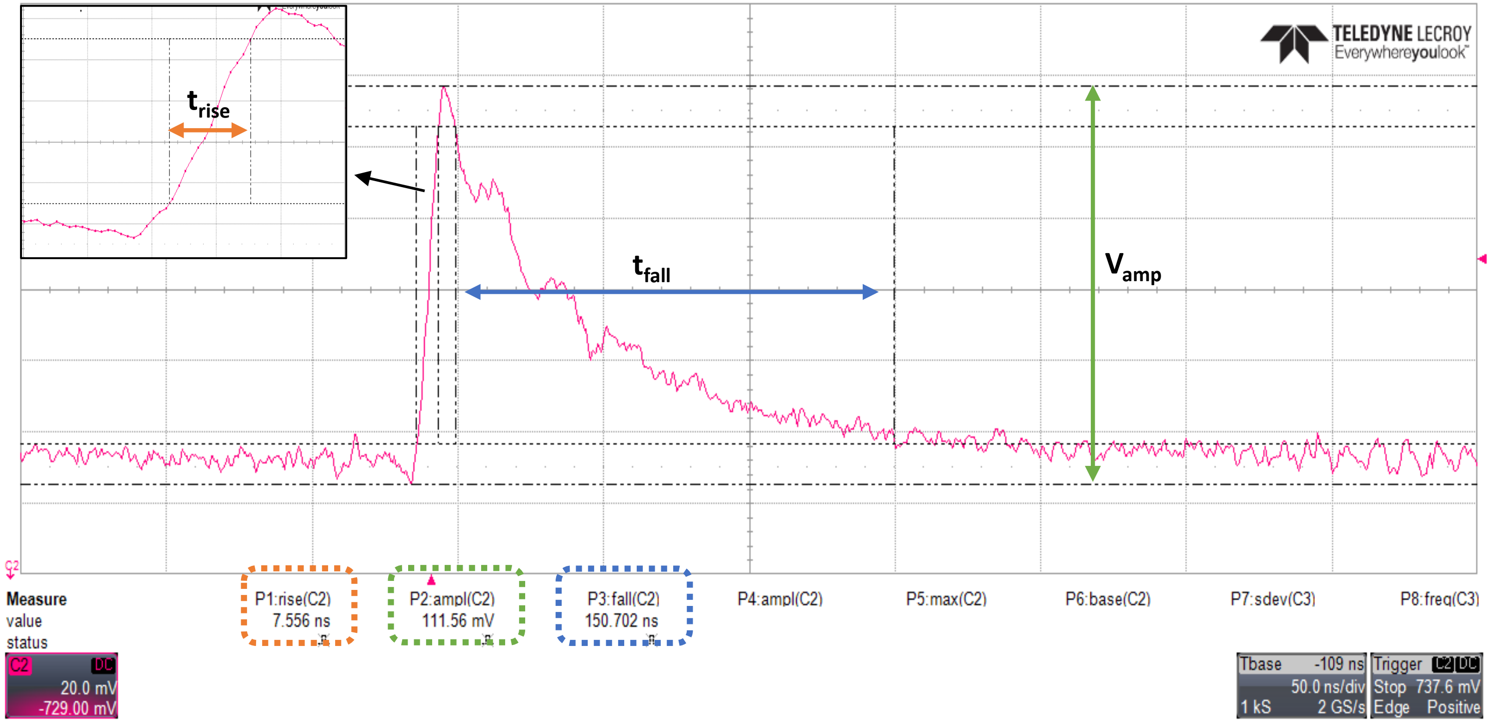


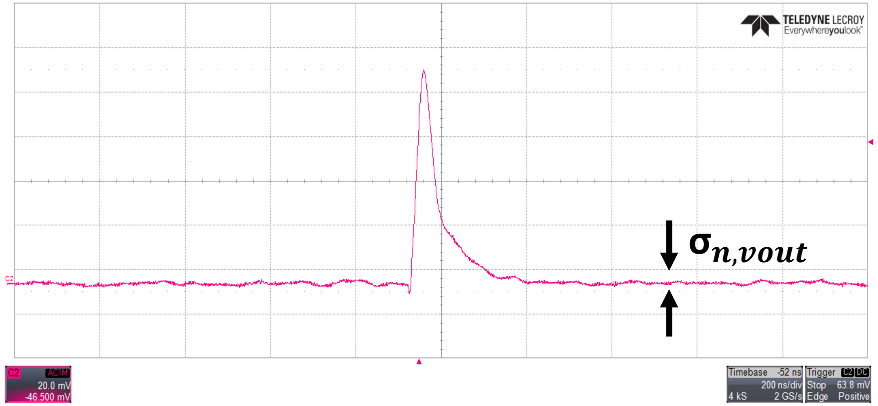


The SuperPixel:

- **Two** mirrored pixels with adjacent digital parts
- **35x35 µm²** pixel size with **20x20 µm²** anode size
- **Half-analog** and **half-digital** pixel
- **Fully-custom** design for **analog** part, **RTL** design and synthesis for **digital part**

MIRA I CSA Transient Response - Measurements





With active probe:

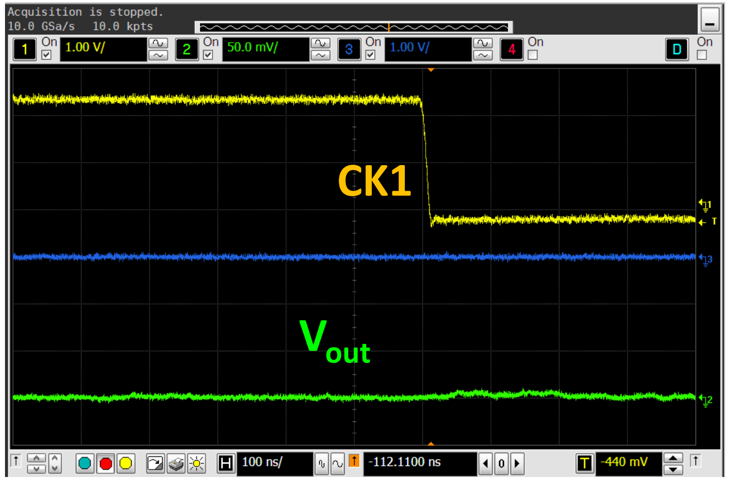
- **Slow** Mode
- $\mathbf{t_{rise}} = 7\ \mathrm{ns}$, $\mathrm{t_{fall}} = 150\ \mathrm{ns}$
- $\mathbf{t_{width}}|_{\mathbf{1\%peak}} = 261\ \mathrm{ns}$
- $\mathrm{V_{amp}} = 112\ \mathrm{mV} \rightarrow \mathbf{Q_{in}} = 4000\ \mathrm{e^-}$

With SMA connection:

- $t_{rise} = 22\ ns$
- $\boldsymbol{\sigma}_{\mathbf{n,vout}} = 750\ \mu\mathrm{V_{rms}}$
- $\mathrm{ENC}_{\boldsymbol{CSA}} = \mathbf{27}\ \boldsymbol{e^-_{rms}}$

MIRA II –Results

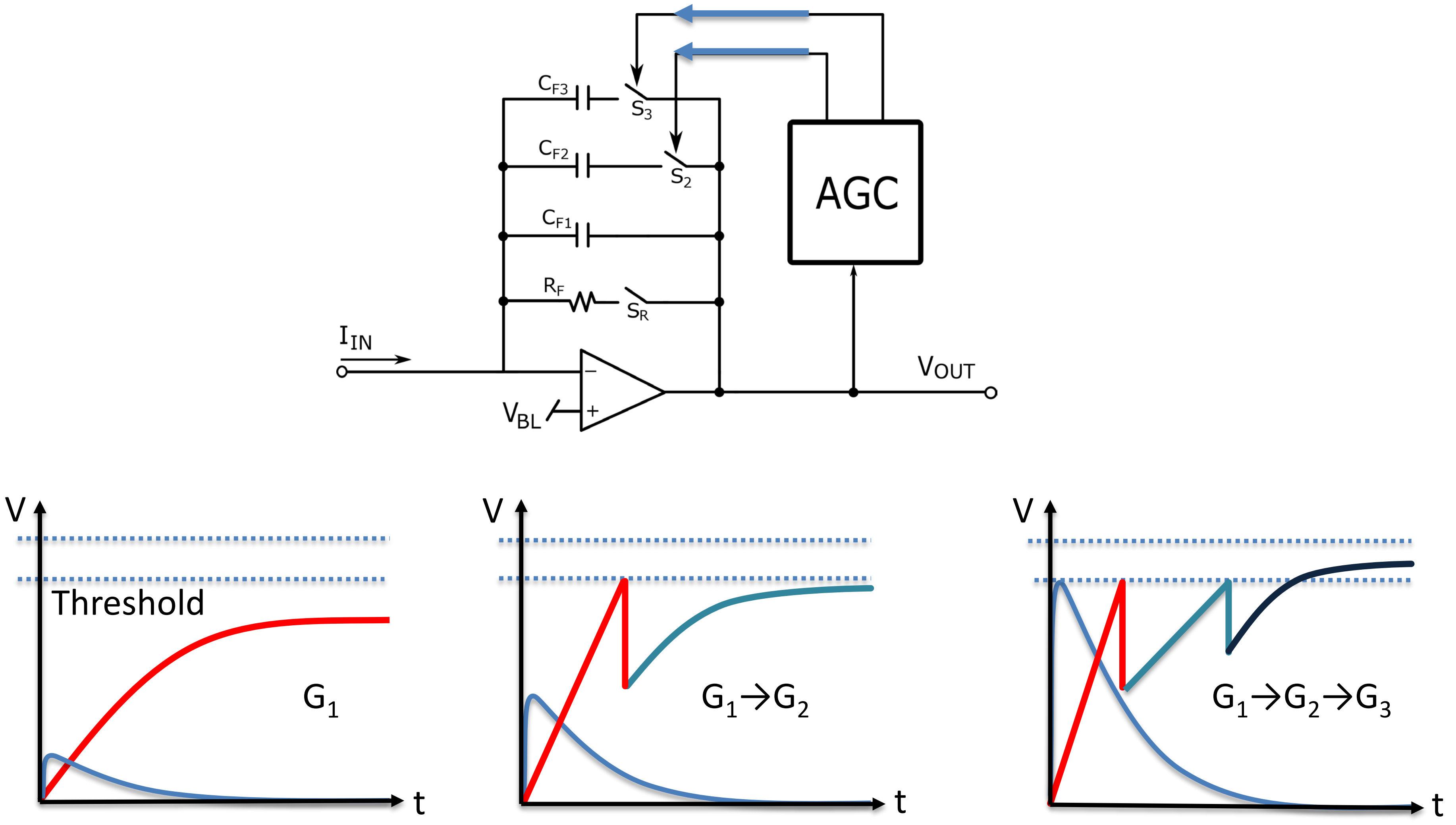
✓ Low-threshold operation



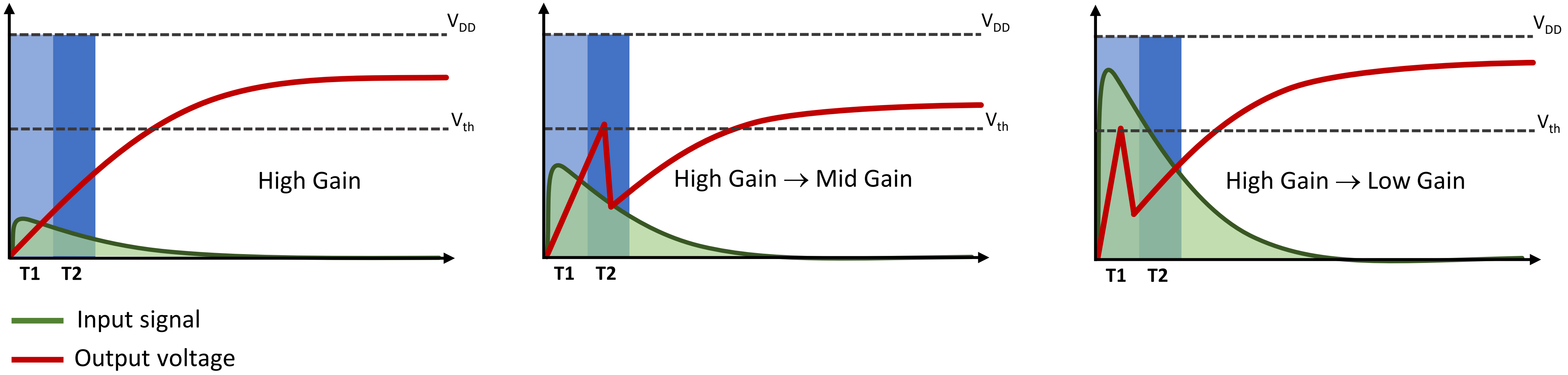
ENC = 20 e^{-}_{rms}

✓ All pixels are configurable and readable

Gain-switching: standard approach



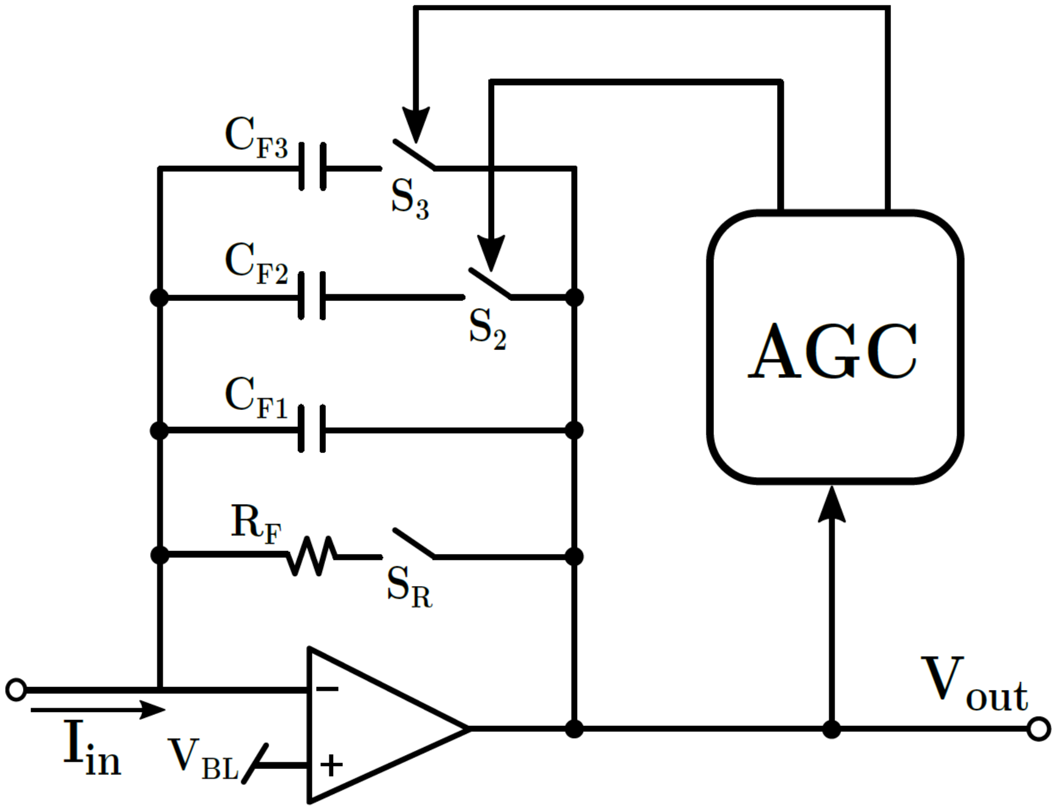
Gain-switching: ‘predictive’ approach

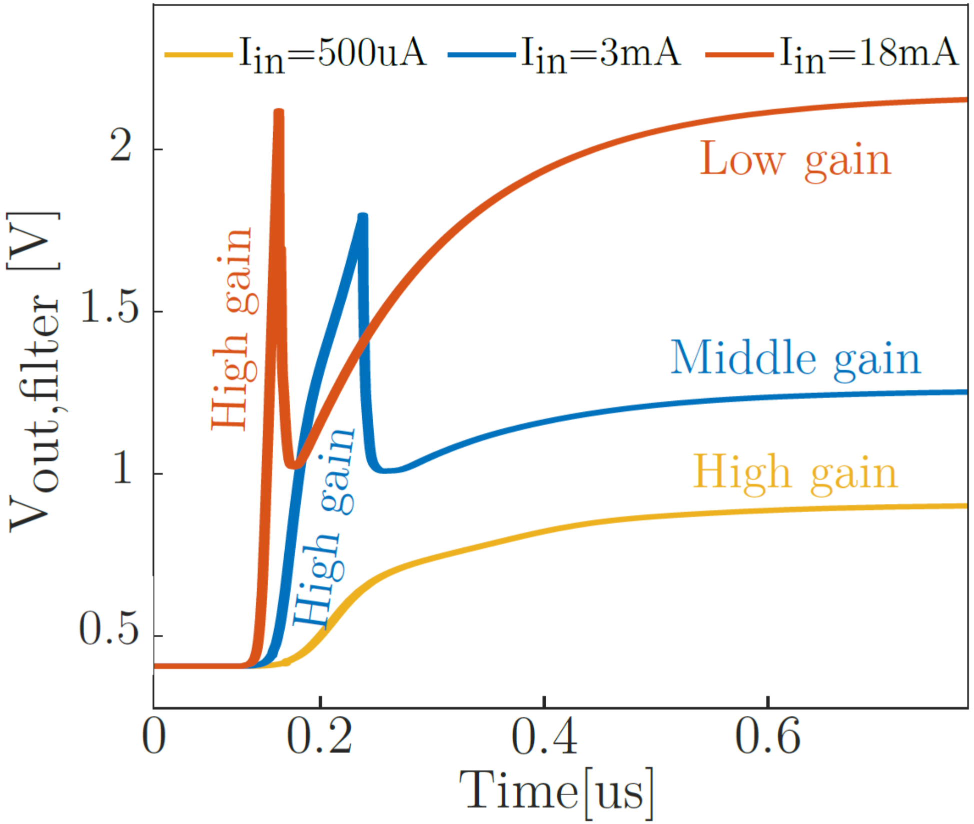


Features:

- Only one gain transition among multiple gains
- Relative freedom in setting the threshold
- Gain-switch decision taken quite early vs. end of integration

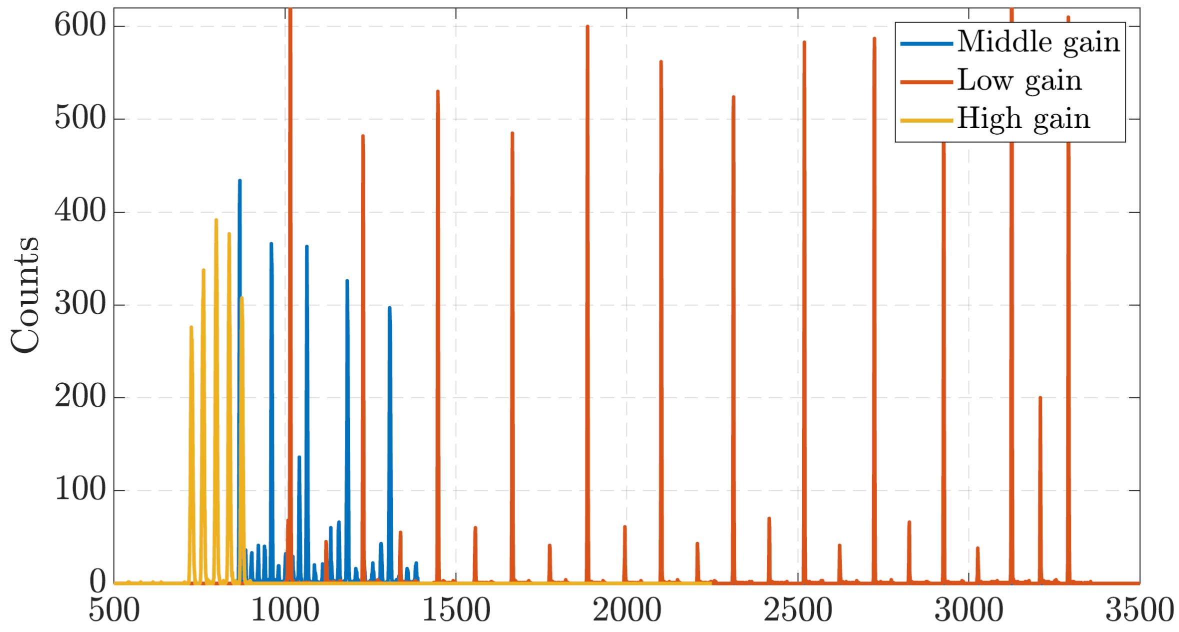
Implementation in a SiPM-readout ASIC

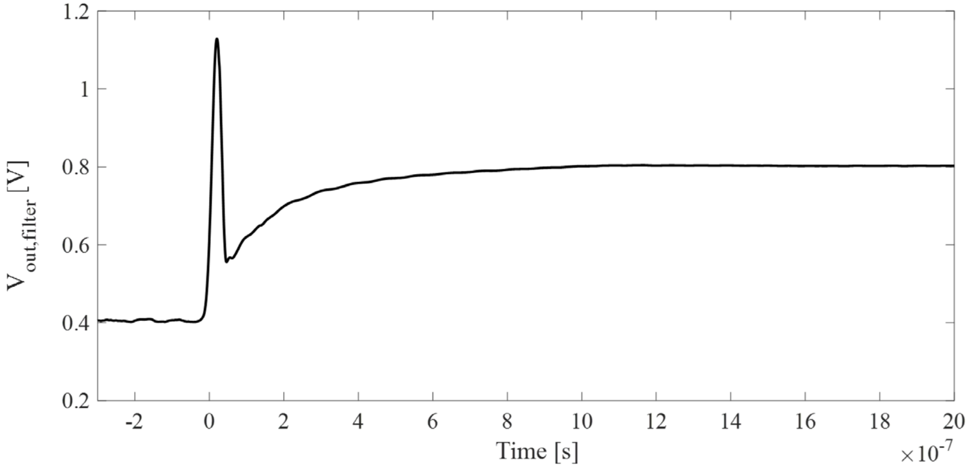


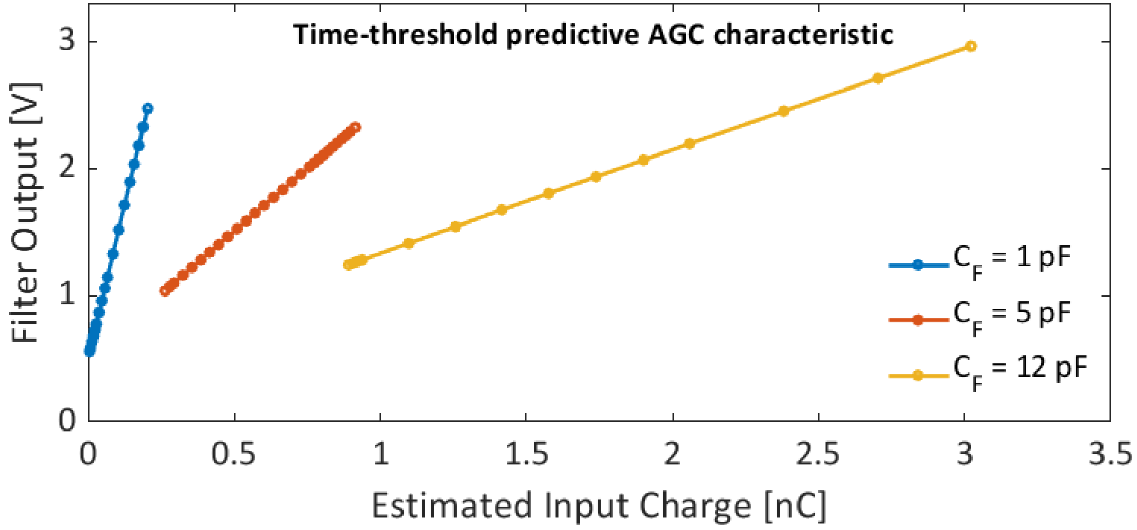


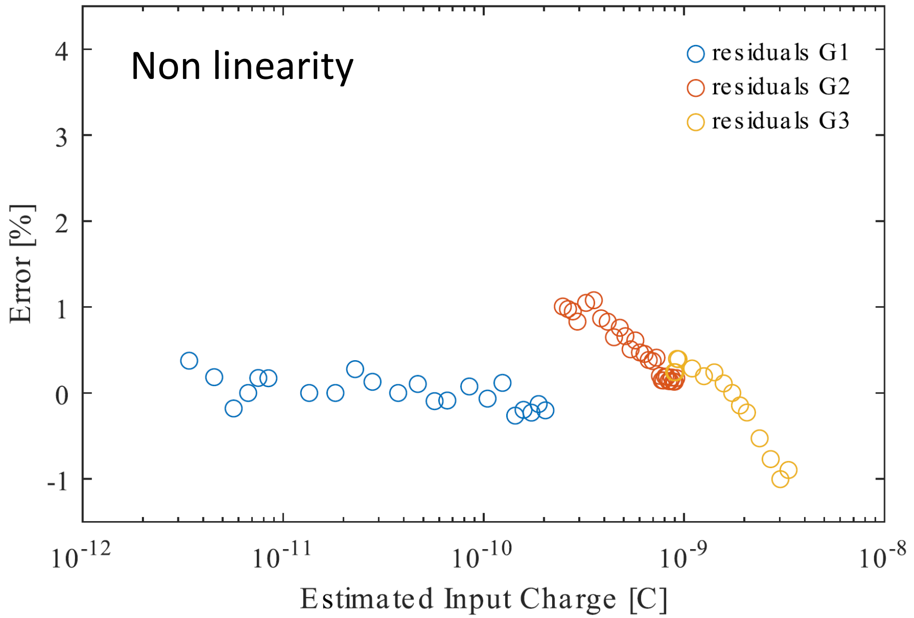
L.Buonanno, D.Di Vita, M.Carminati and C.Fiorini, "GAMMA: A 16-Channel Spectroscopic ASIC for SiPMs Readout with 84-dB Dynamic Range", (2021) IEEE Transactions on Nuclear Science, 68 (10), pp. 2559-2572.

Experimental results









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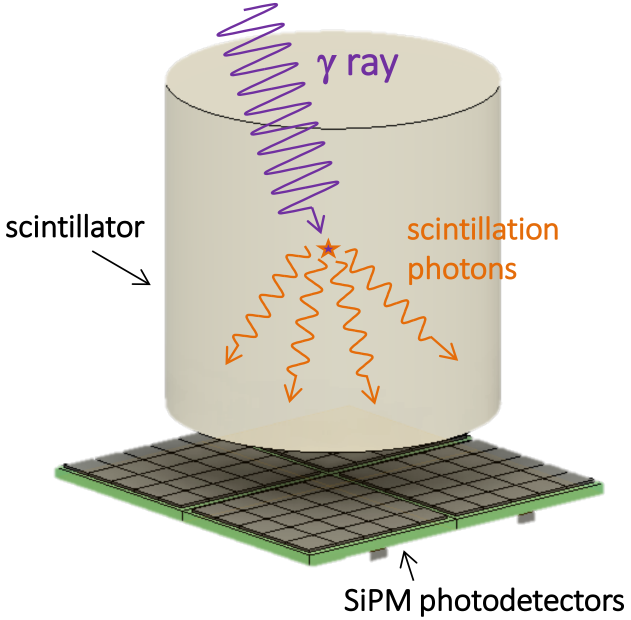
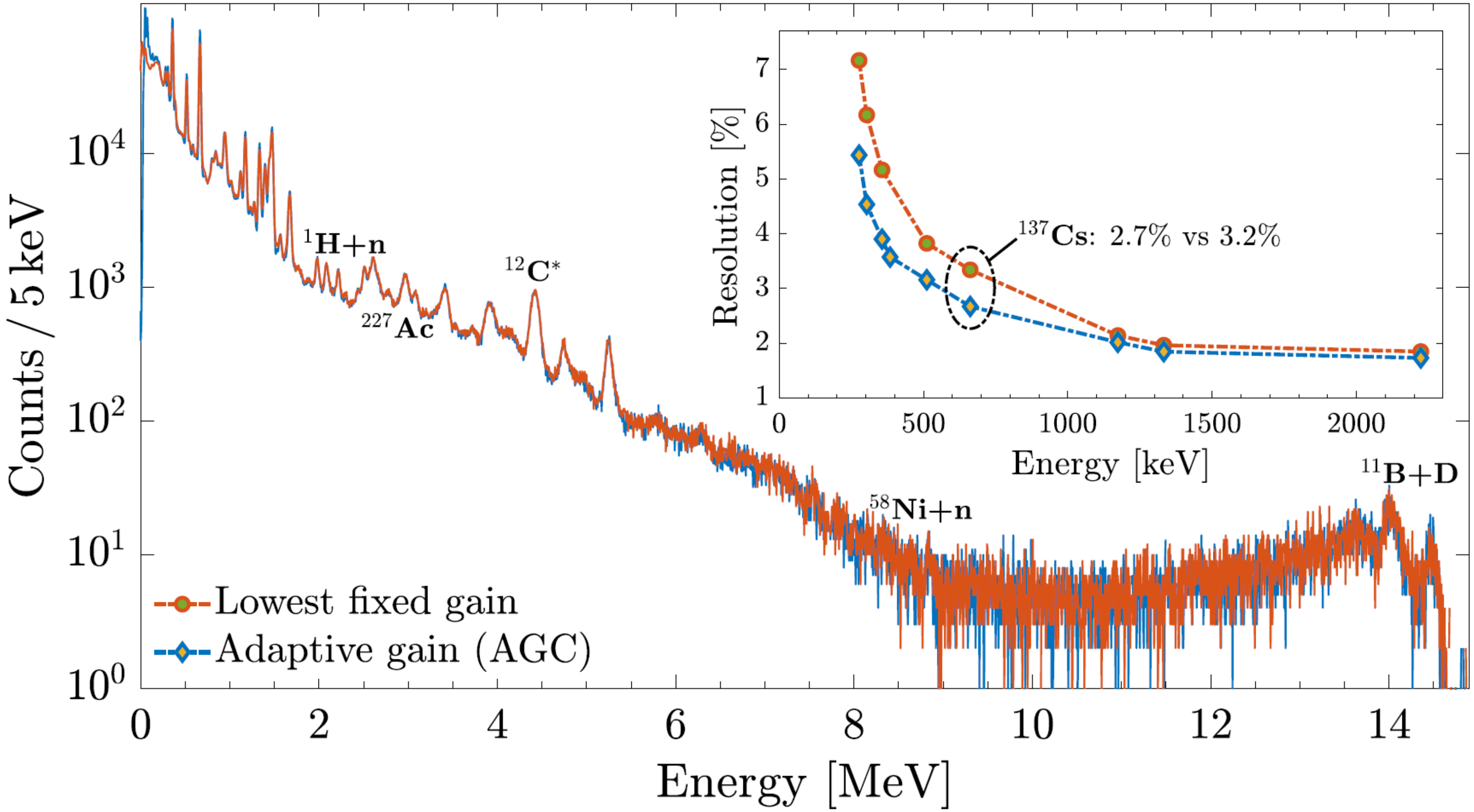
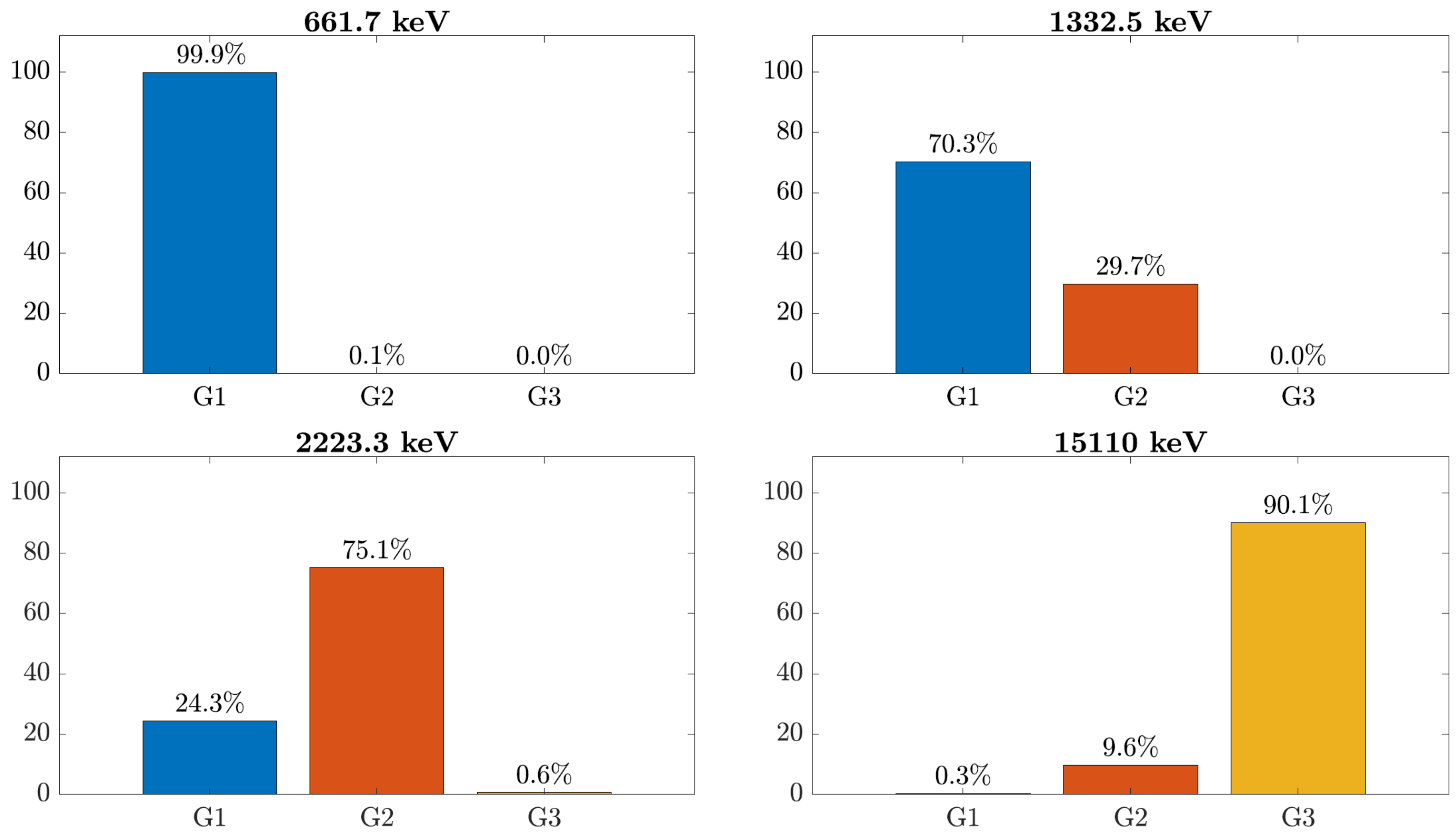
Implementation in a gamma-ray detector



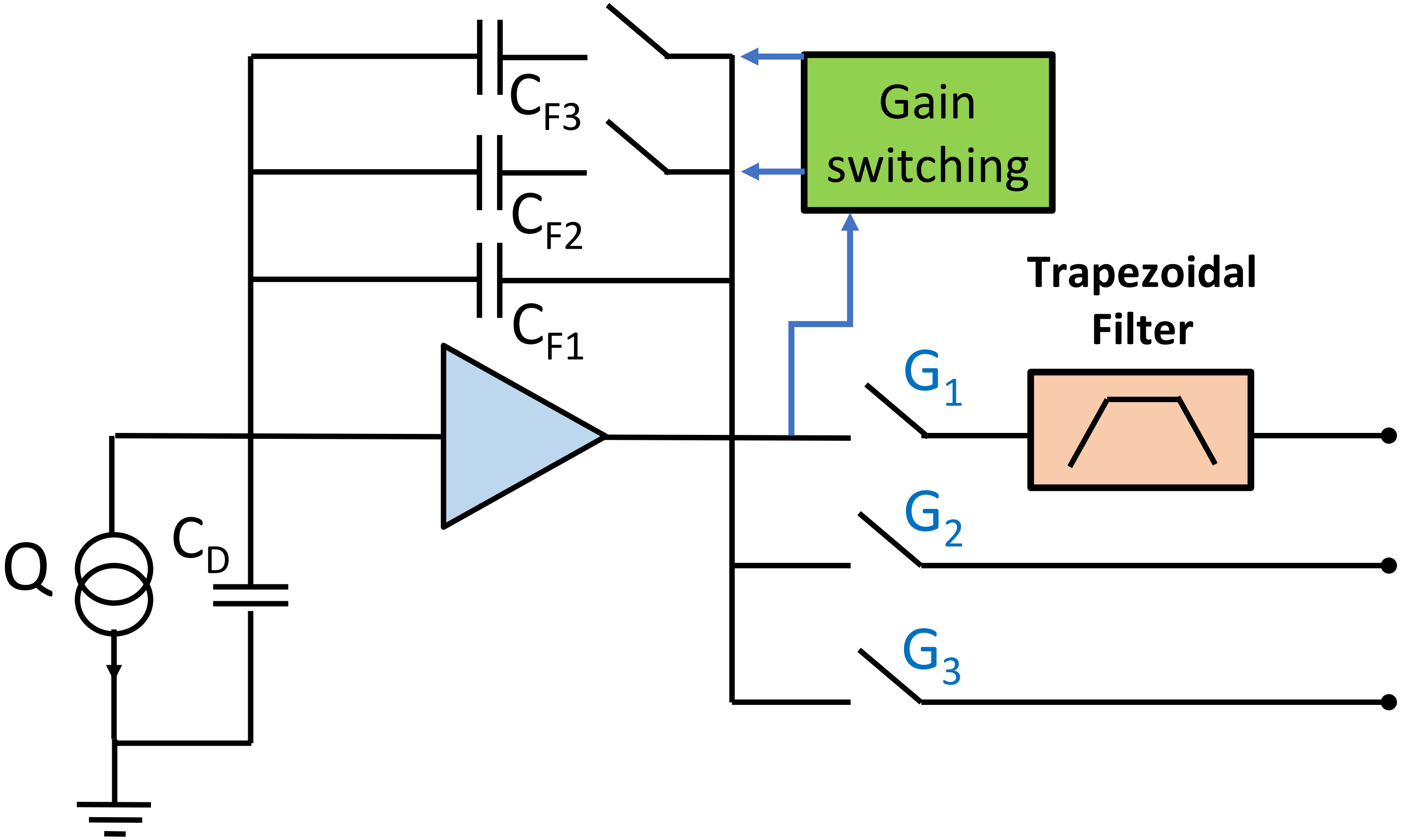


M. Agnolin *et al.*, "A γ-Ray Detector Based on a 3" LaBr3:Ce:Sr Crystal with SiPM Readout for 80 keV – 16 MeV Energy Range with Position Sensitivity for Doppler Correction," in *IEEE Transactions on Nuclear Science*, doi: 10.1109/TNS.2023.3312424.

Gain switching statistics



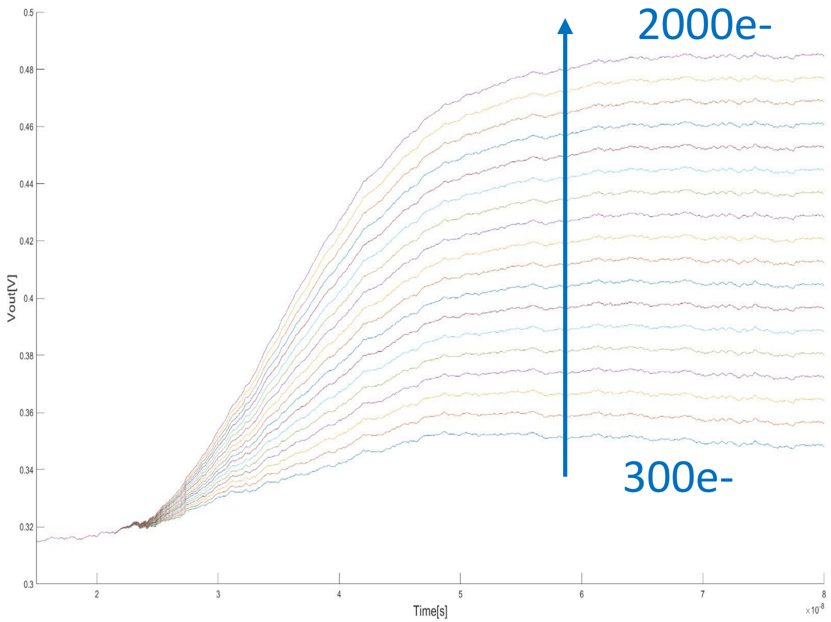
Study of FE in 65nm for EuXFEL detectors



Range1: 1-20ph @1keV

Range2: 20-1000ph @1keV

Range3: 10^3-10^4ph @1keV



Preliminary noise evaluations...

Range1: 1-20ph @1keV

ENC @50ns T_{int}: 31e- rms (S/N ~ 9.0 @1keV)

ENC @100ns T_{int}: 26e- rms

ENC @150ns T_{int}: 24e- rms

Range2: 20-1000ph @1keV

ENC: 246e- rms $\rightarrow$ 1.1ph @1keV

Range3: 10^3-10^4ph @1keV

ENC: 1880e- rms $\rightarrow$ 6.7ph @1keV

(C_T=130fF, Range1,2 do not include 2nd stage noise contributions)

Wrap-up..

Polimi team is willing to contribute to the development of FE solutions for detectors for EuXFEL and to collaborate with other teams for new large scale ASICs.

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