20th iWoRiD
International Workshop on Radiation Imaging Detectors

Experimental Performance of a Highly-Innovative Low-Noise Charge-Sensitive Preamplifier With Integrated Range-Booster

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Outline

Area: Gamma and Particle spectroscopy with solid state detectors for research in nuclear physics

Nuclear spectroscopy setups and issues

TRACE @ LNL

The multi-channel fast-reset CSP ASIC

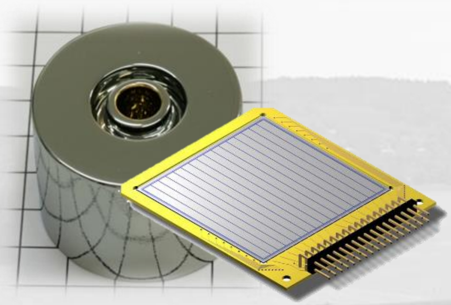
The fast-reset technique

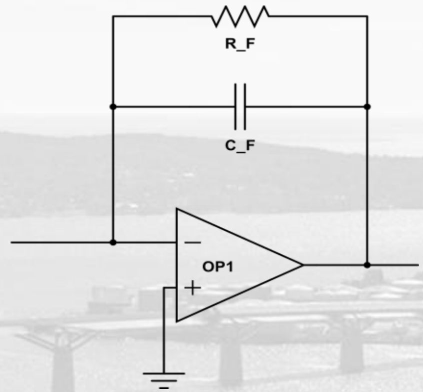
Experimental results

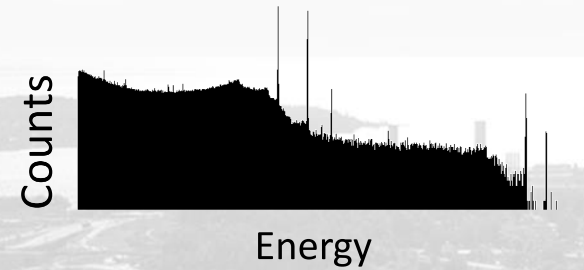
Conclusions

GALILEO @ LNL

Spectroscopic Chain





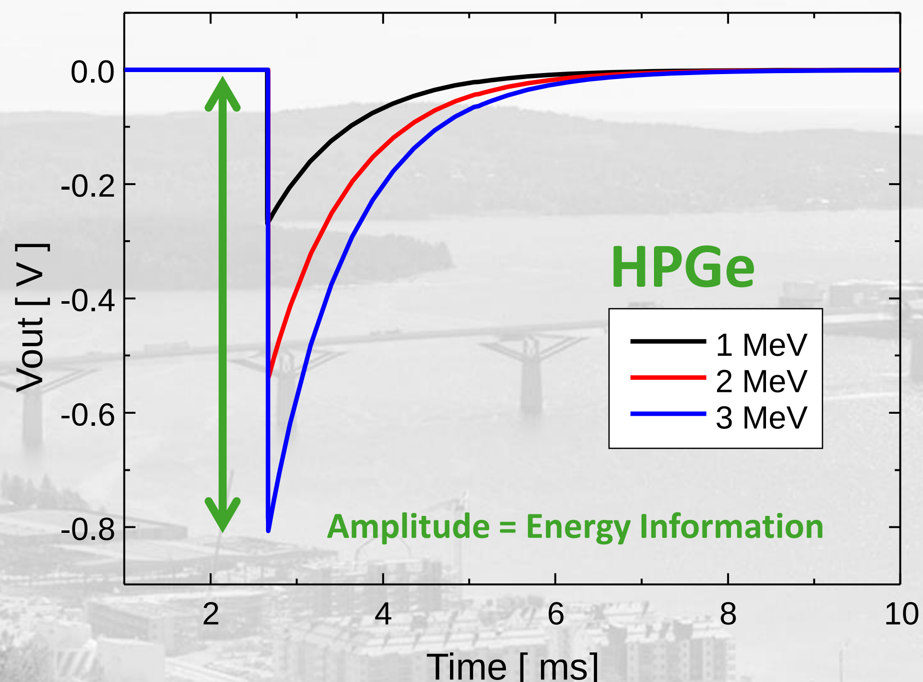


Solid-state detector → **Charge-Sensitive Preamplifier** → **Amplifier and MCA or ADC with digital filtering**

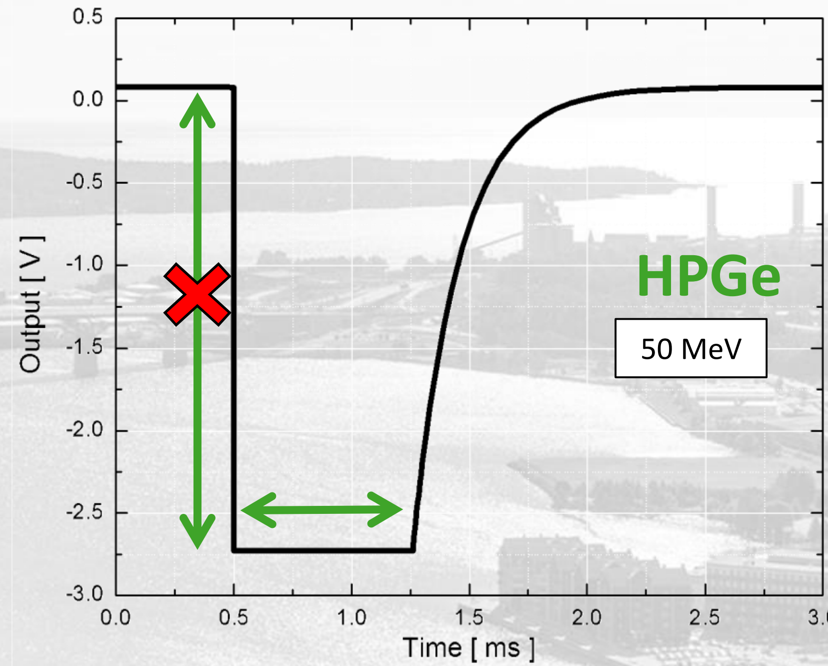
$$i(t) = Q \cdot \delta(t)$$

$$Q_{Emitted} \propto E_{Event}$$

Effects of the saturation on the signal shape of a CSP

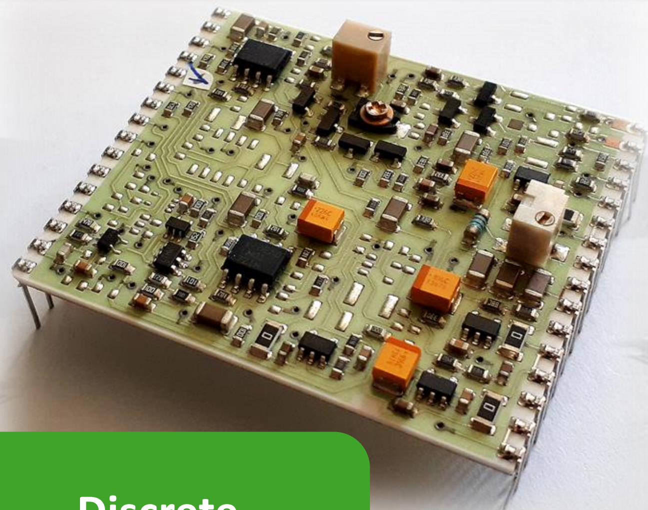


- Signal amplitude proportional to the energy deposited in the detector
- Decay constant determined by the RC product of the CSP



- Corrupted energy information
- Dead time that can be much longer than the decay constant of the preamplifier

Towards a progressive integration of the front-end electronics

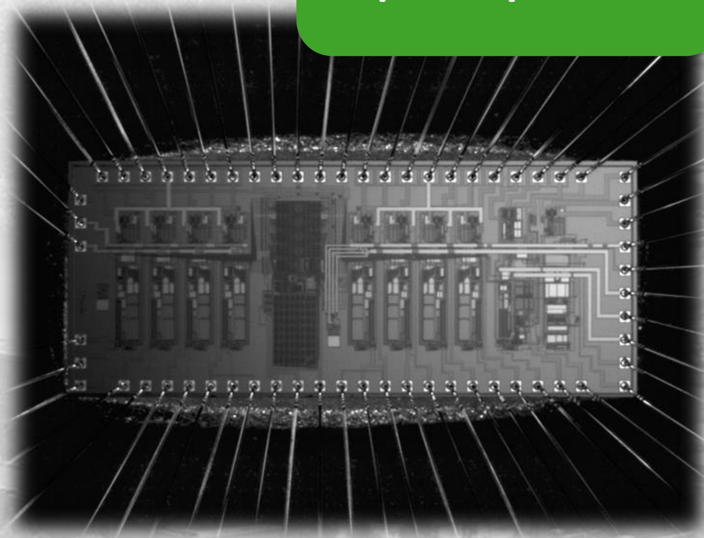


Discrete preamplifiers

- Not suitable in case of high channel density
- Components tolerant to higher bias voltages -> High dynamic range
- Higher power consumption
- Design flexibility

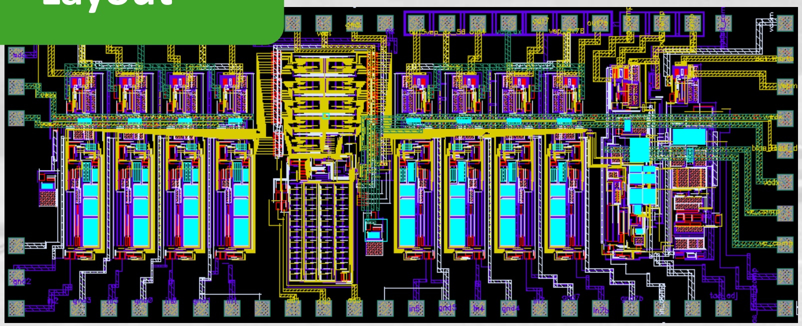
Integrated preamplifiers

- Suitable in case of high channel density
- Components tolerant to lower bias voltages -> Low dynamic range
- Low power consumption
- Radio-purity

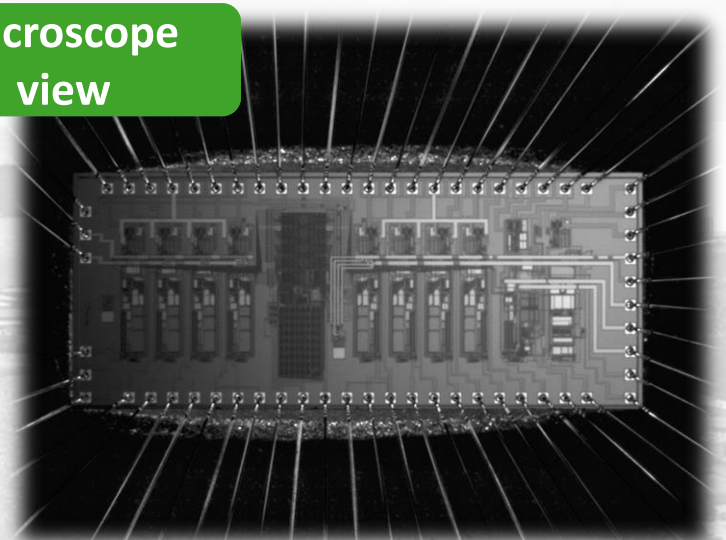


The Fast-Reset Integrated preamplifier

Layout



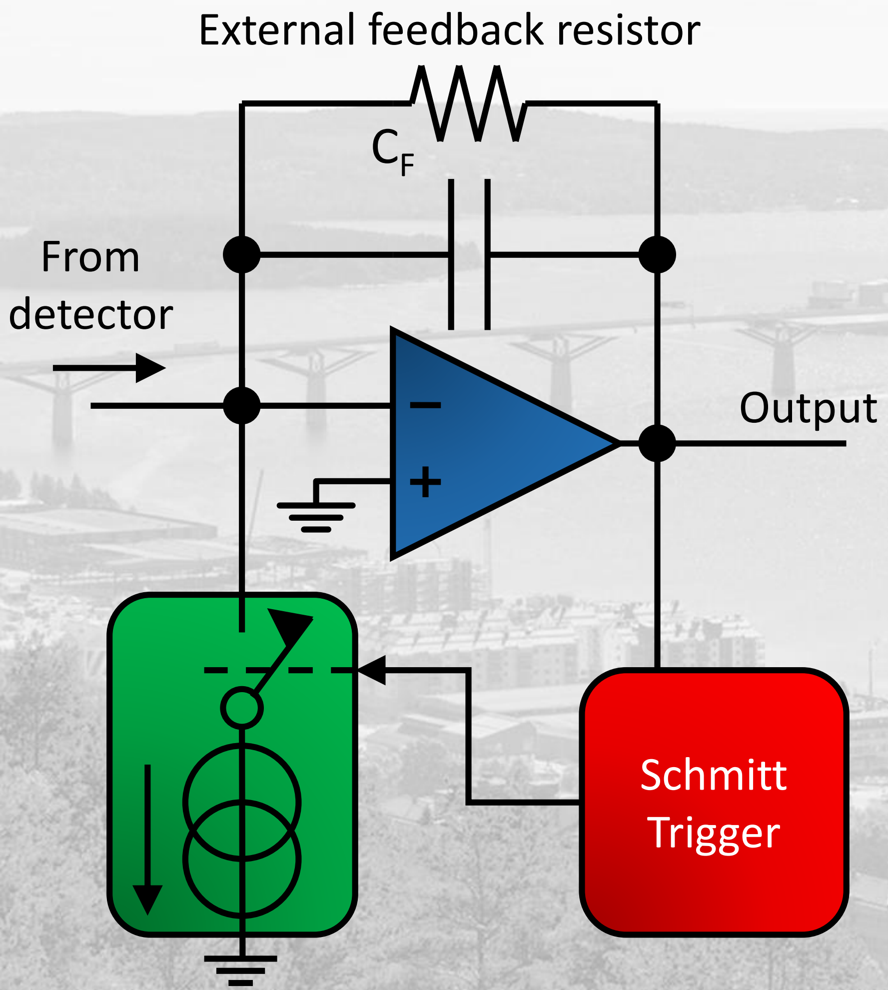
Microscope view

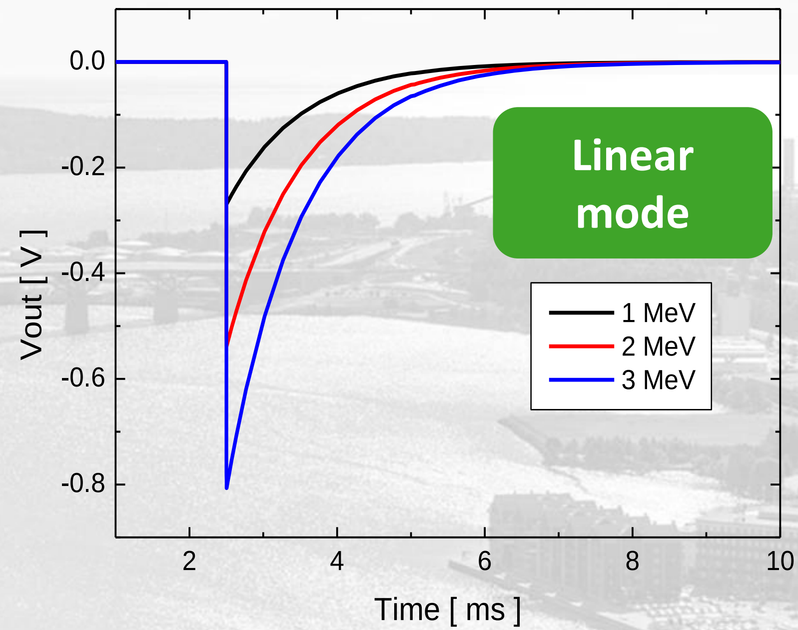


- Realized in AMS C35 technology
- 8 channels for anodic signals and 1 channel for cathodic ones
- Power consumption: 12 mW/ch
- Risetime: 10 ns (4 pF det. And 1 pF FB)
- Power supply: ±2.5V
- Area = $10mm^2$

- Carrier: PLCC68
- Digital slow control with I2C engine
- Separate power rails for cross-talk reduction
- Equipped with Fast-Reset circuit
- Only one external component: the feedback resistor

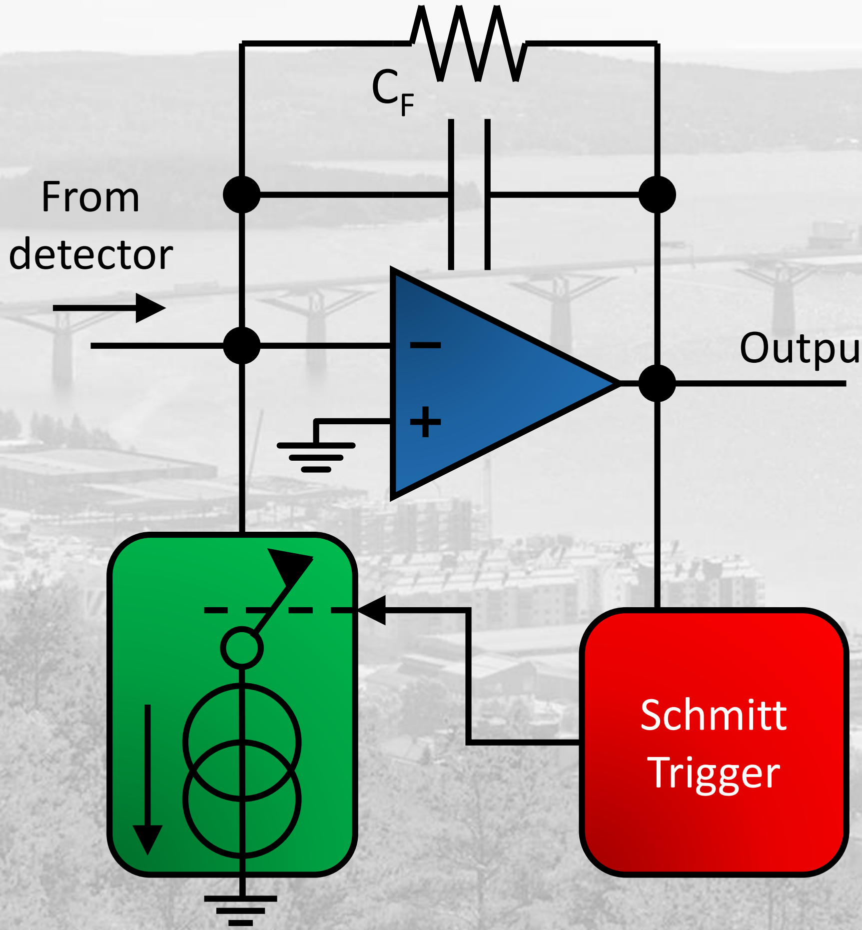
The Fast-Reset Integrated preamplifier

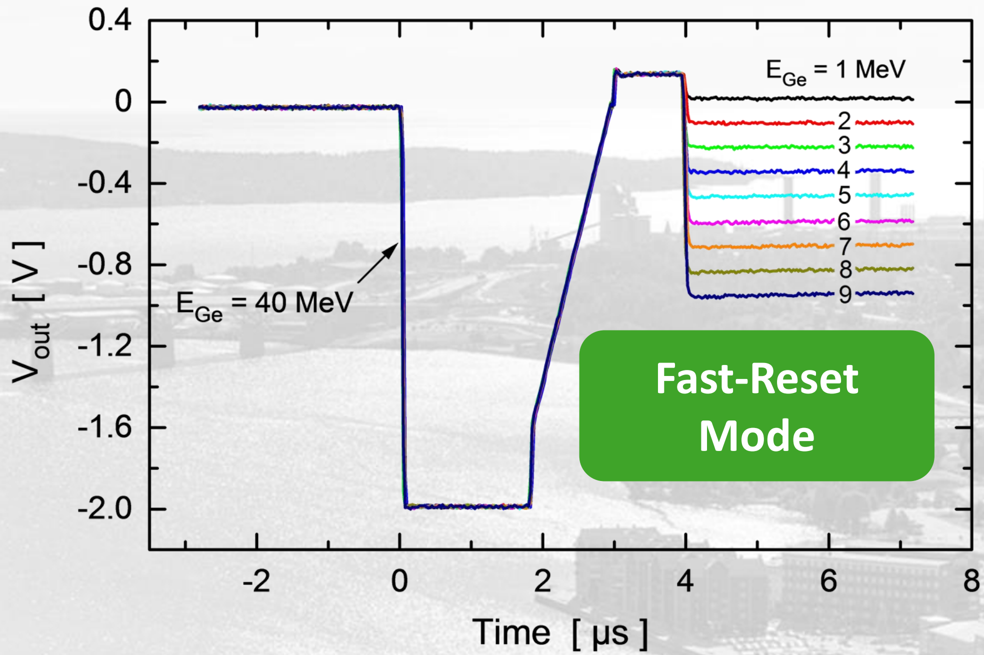




- The Fast-Reset preamplifier is a CSP equipped with a Schmitt Trigger and a Current sink
- For under-threshold signals it works like a normal CSP
- In case of saturation the current sink is activated

The Fast-Reset Integrated preamplifier

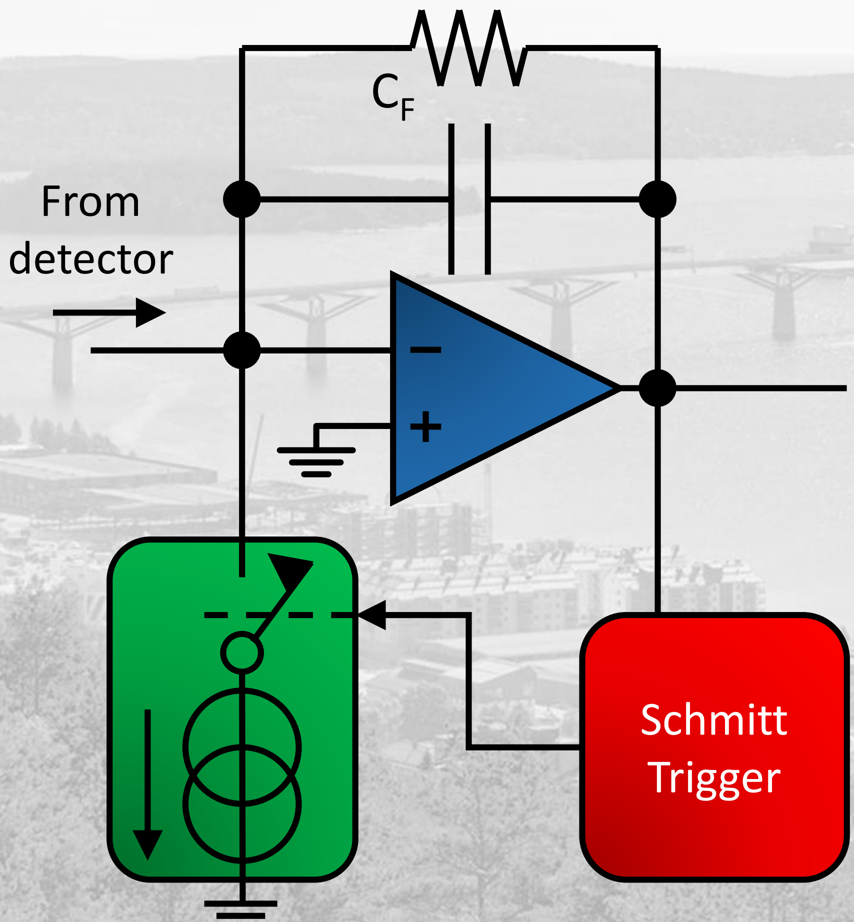




- The Fast-Reset preamplifier is a CSP equipped with a Schmitt Trigger and a Current sink
- For under-threshold signals it works like a normal CSP
- In case of saturation the current sink is activated

The Fast-Reset mode: Not only dead-time reduction But also High-resolution Spectroscopy

External feedback resistor



Charge-conservation principle

Constant and controlled Current generator

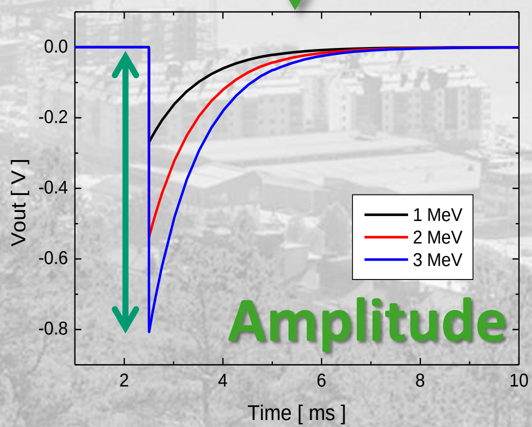
High-resolution spectroscopy with Time-over-Threshold algorithm

$$\Delta T = \frac{Q_{TOT}}{I_{RESET}}$$

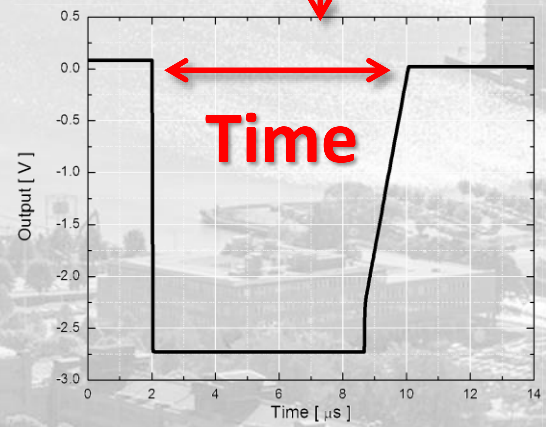
The Fast-Reset mode:
Not only dead-time reduction
But also High-resolution
Spectroscopy

Combining offline the information collected with the two operative modes we can reconstruct the energy spectrum over an extended range

Energies under the saturation threshold < 10 (40) MeV

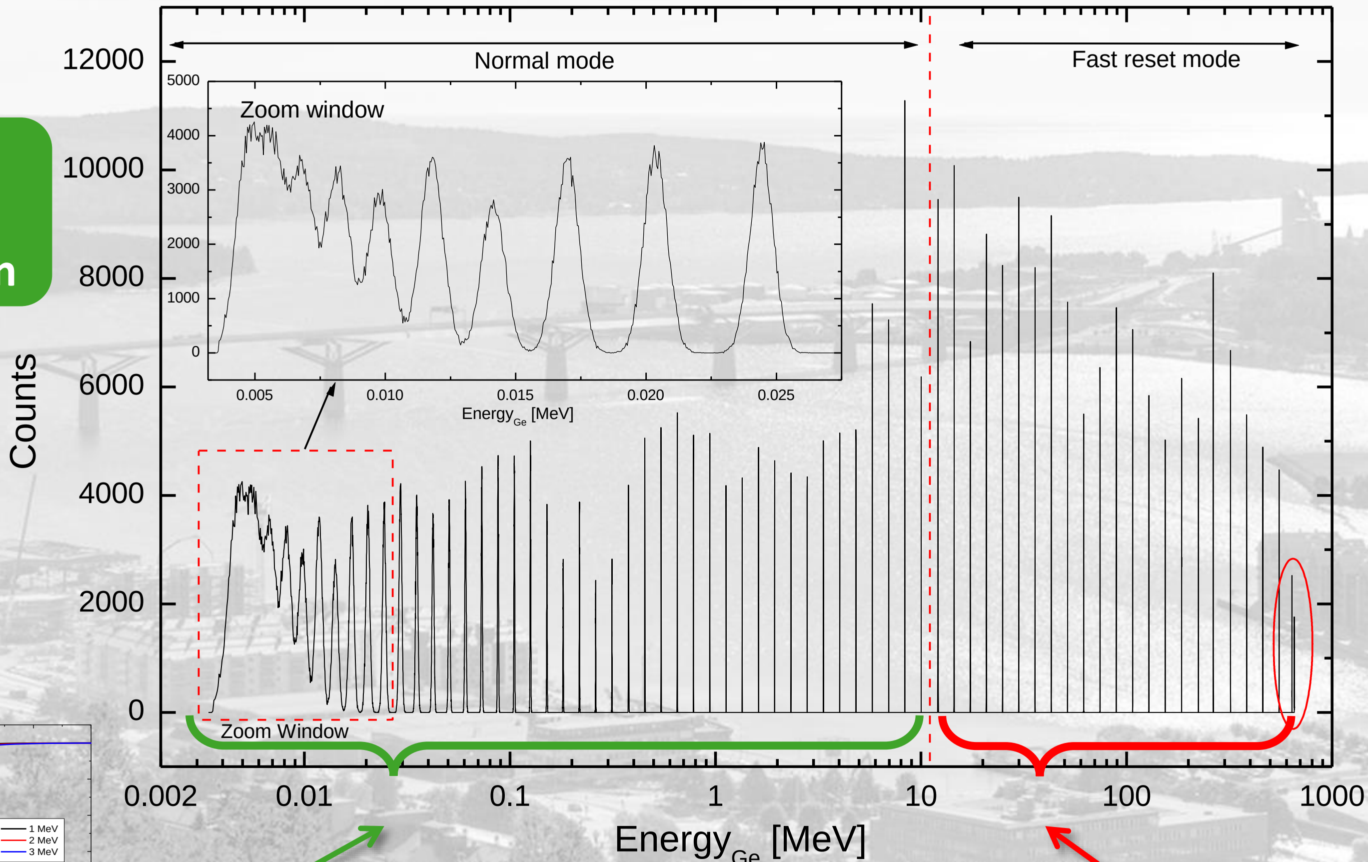


Energies over the saturation threshold > 10 (40) MeV

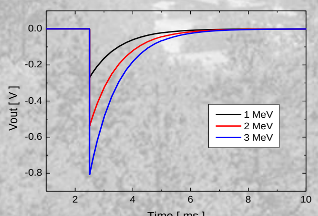


The Fast-Reset mode: Not only dead-time reduction But also High-resolution Spectroscopy

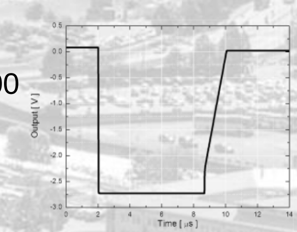
1.1 keV FWHM resolution



0.2% FWHM Resolution Or better



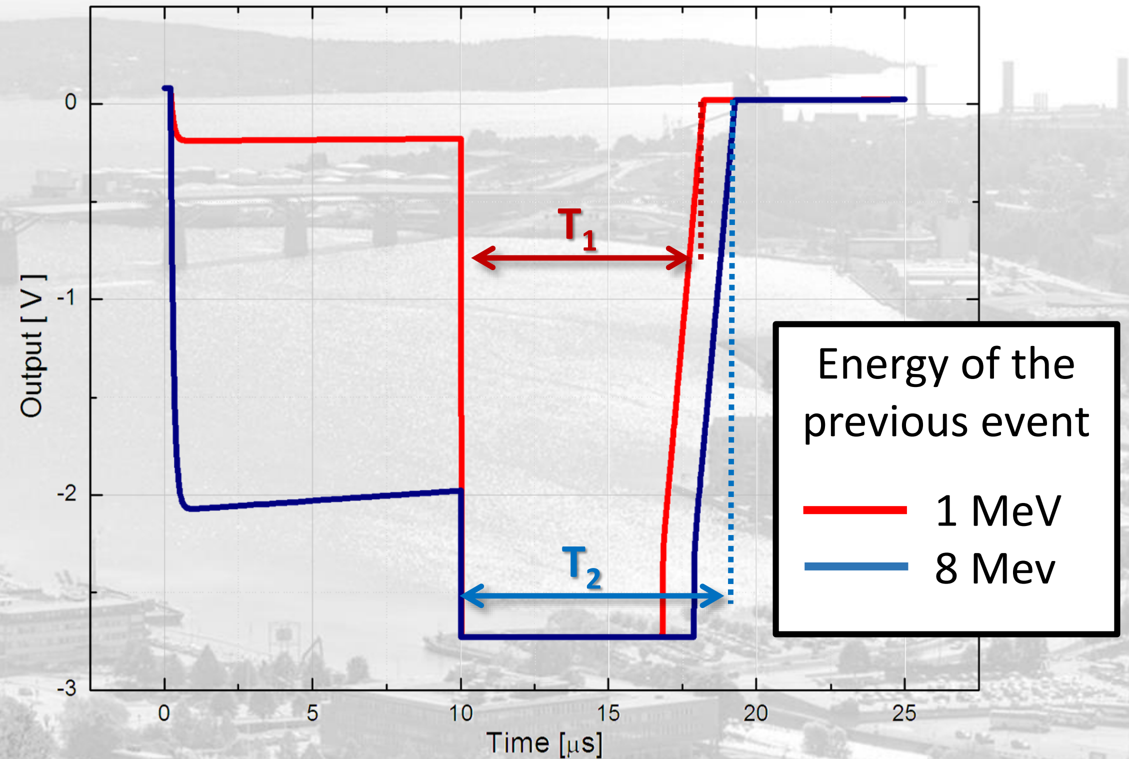
Amplitude



Time to Amplitude

Dependency of the energy measurement from the baseline value

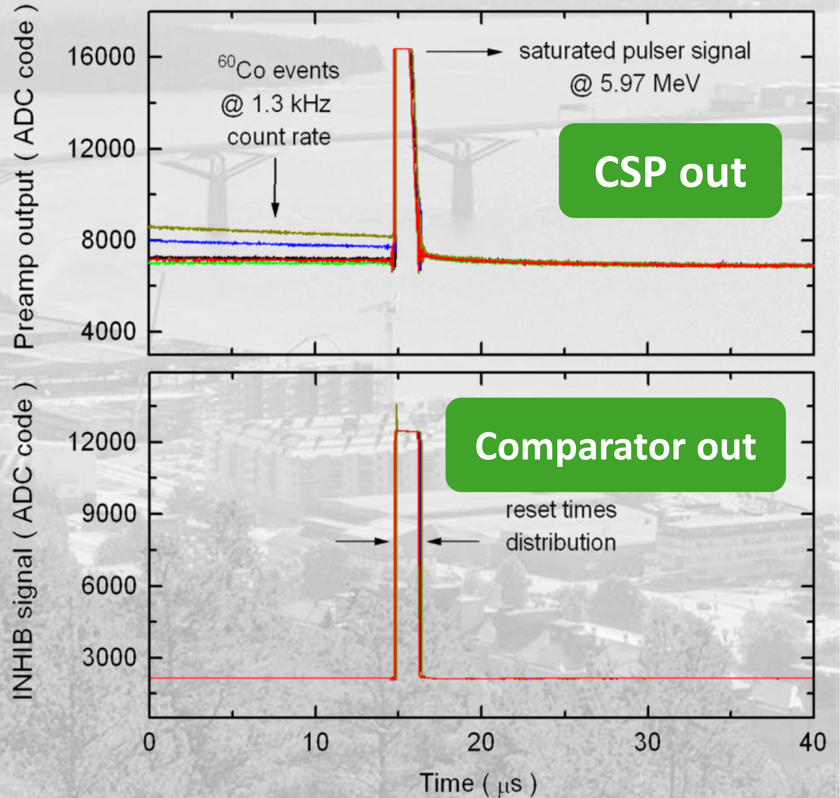
- The digital TOT signal depends on the residual charge on C_F before the reset process
- **Need for an algorithm to correct this dependency**
- Off-line digital correction: easy to implement but expensive in computational terms

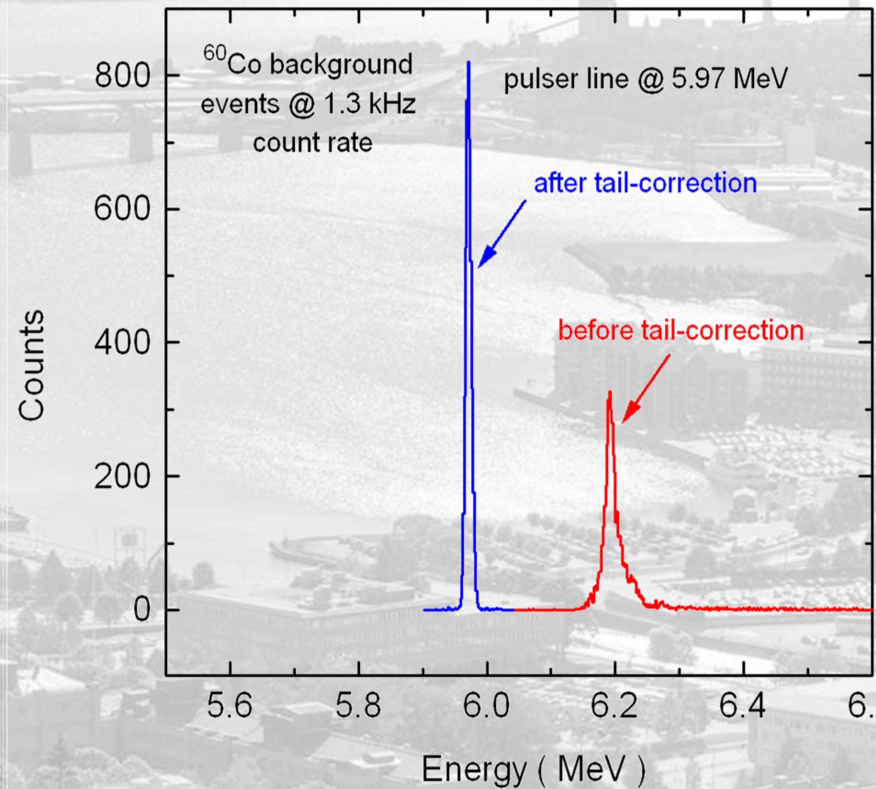


Dependency of the energy measurement from the baseline value

Pile-up effects at medium counting rate

1.3 KHz

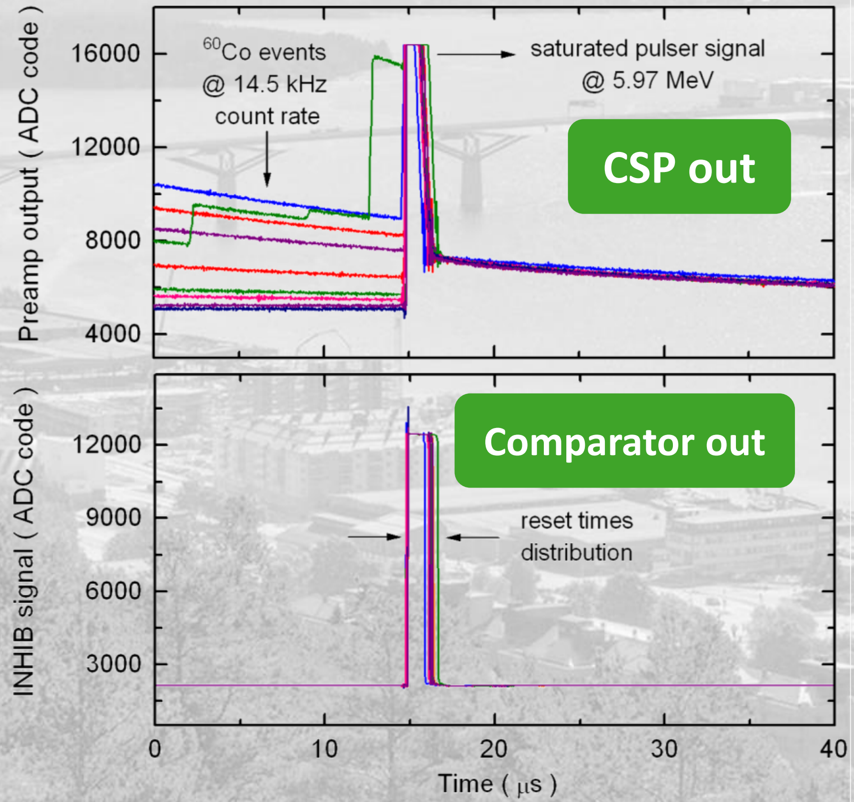


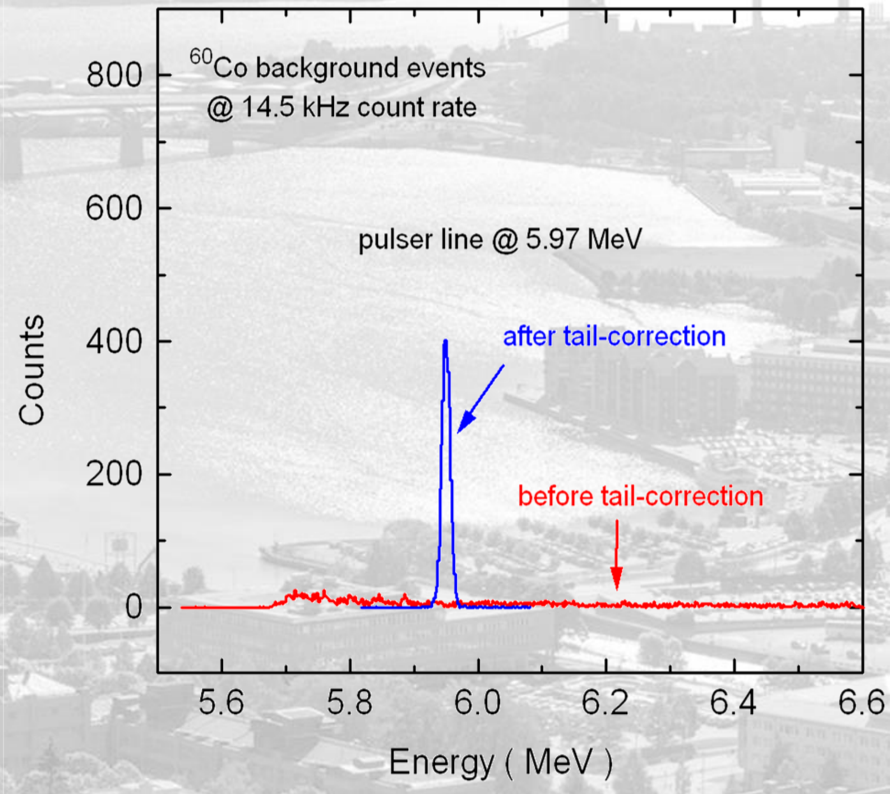


Dependency of the energy measurement from the baseline value

Pile-up effects at high counting rate

14.5 KHz

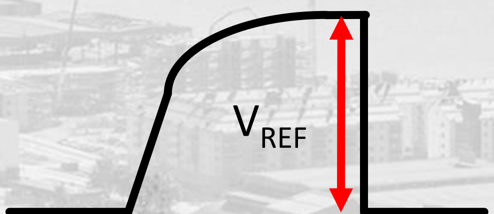




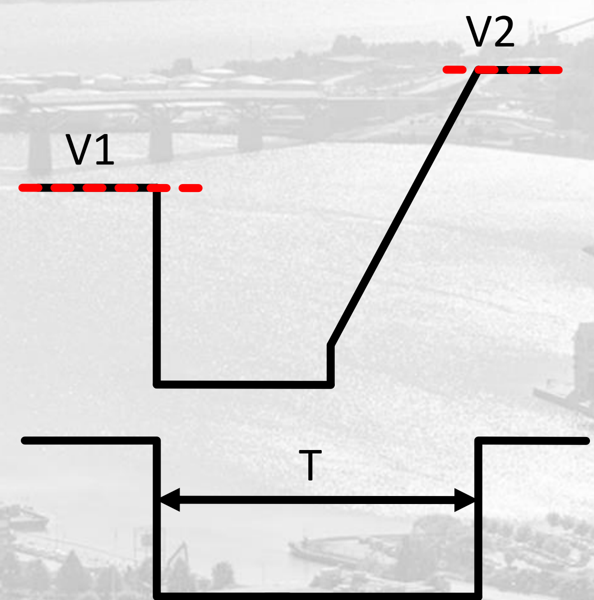
An algorithm to correct the spectra from the baseline dependency

$$E_{DET} \propto V_{REF} = \alpha[I_{RESET} \cdot T - C_F \cdot (V_2 - V_1)]$$

Need to generate an auxiliary signal with amplitude V_{REF} directly proportional to the energy of the last physical event (and that doesn't depend on the residual charge of past events!)



AUXILIARY SIGNAL

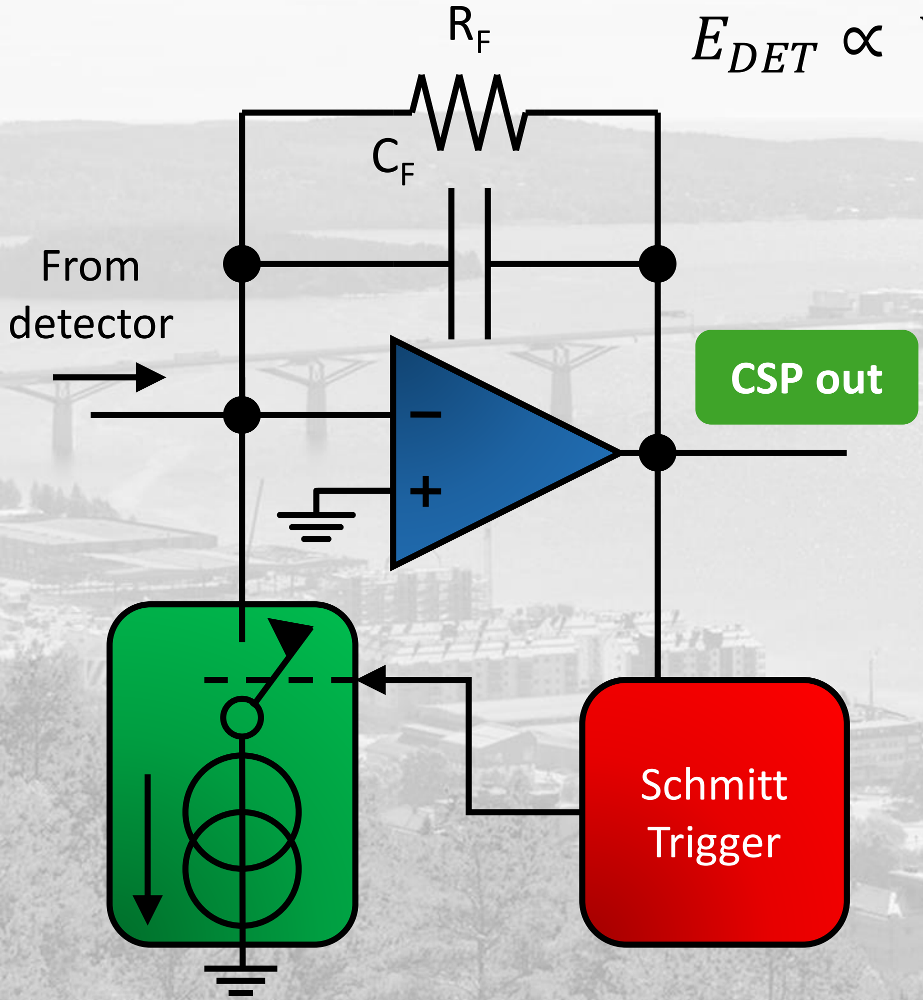


CSP out

Comparator out

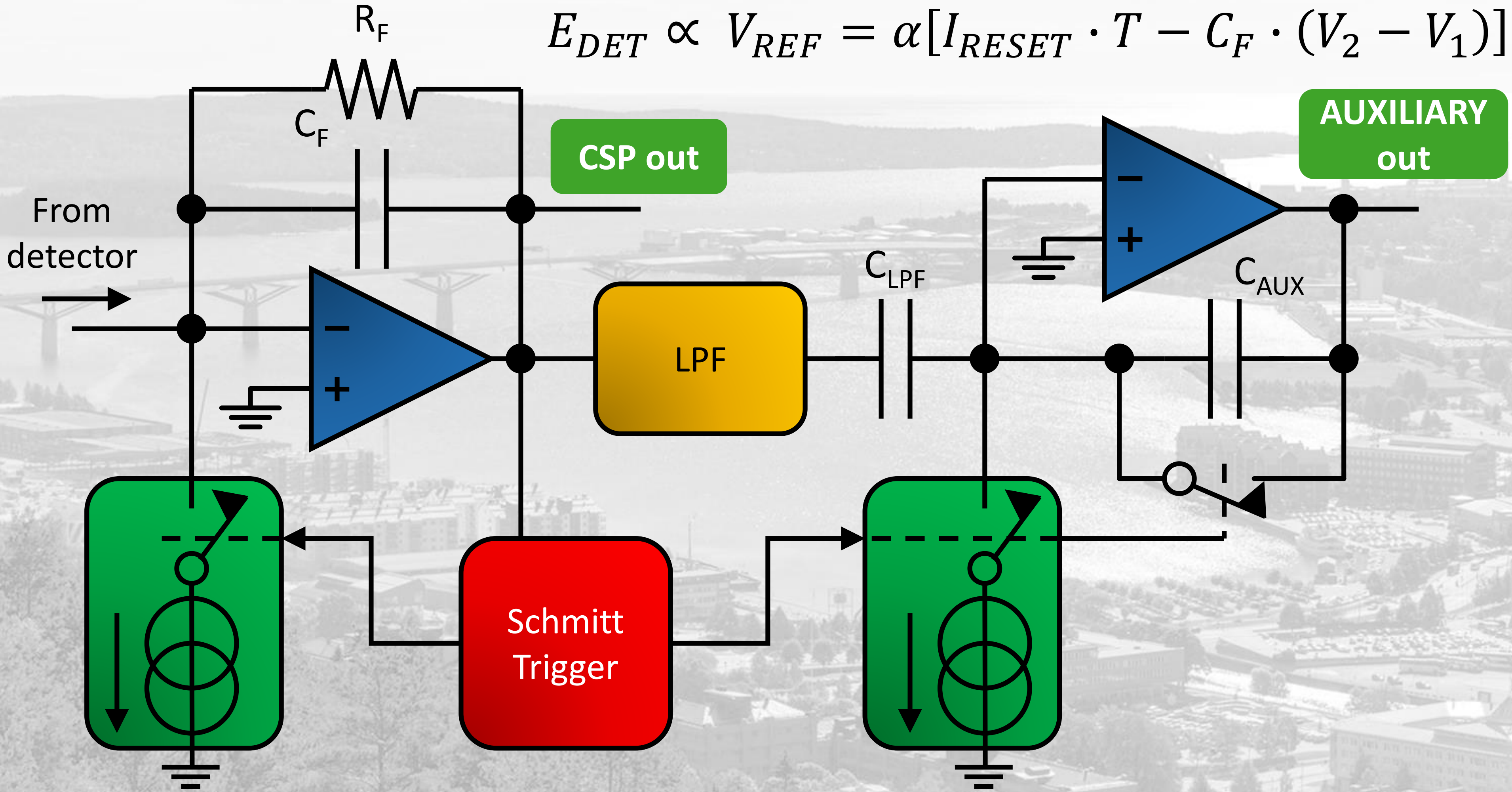
An algorithm to correct the spectra from the baseline dependency

$$E_{DET} \propto V_{REF} = \alpha[I_{RESET} \cdot T - C_F \cdot (V_2 - V_1)]$$



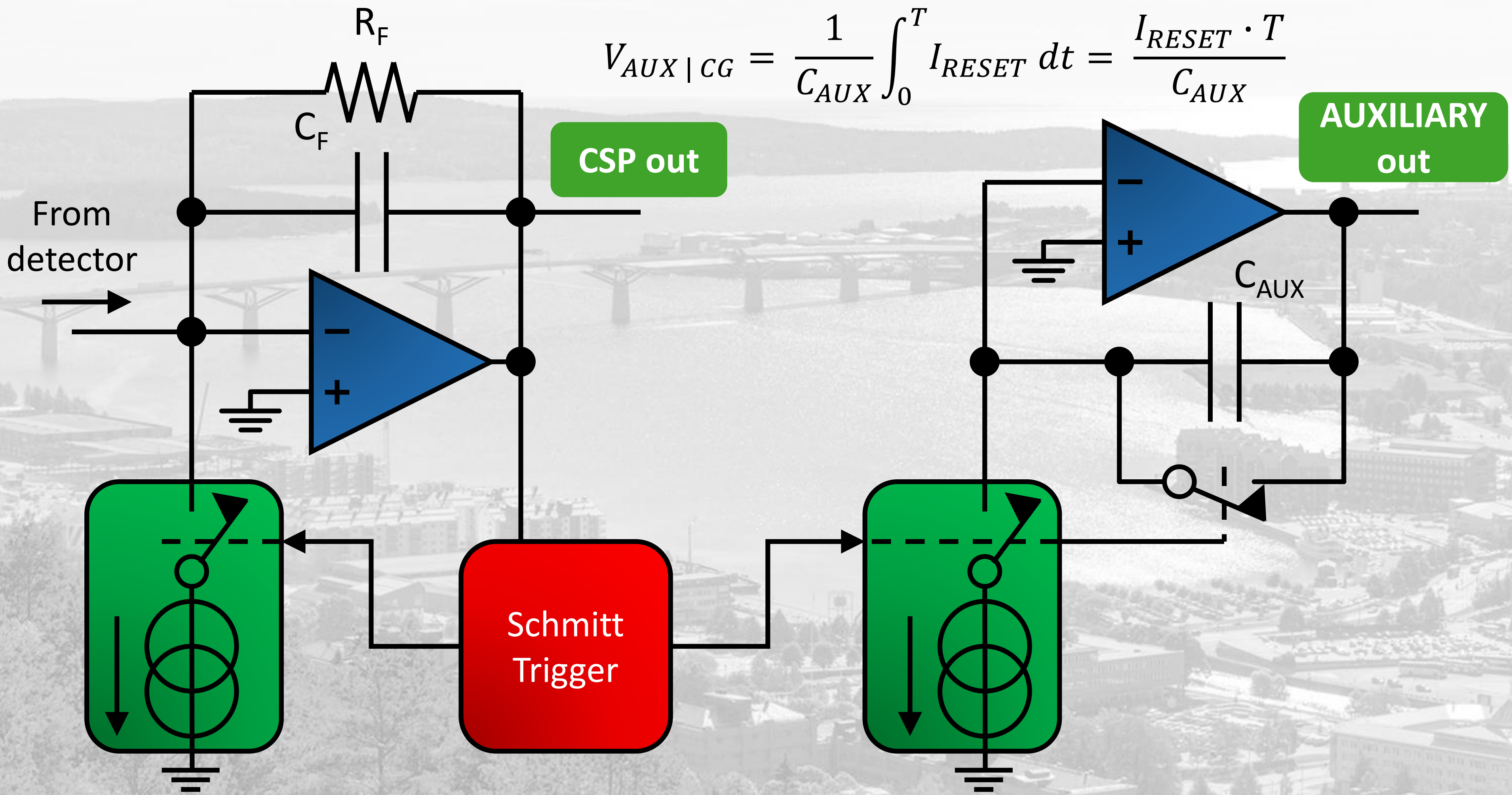
An algorithm to correct the spectra from the baseline dependency

$$E_{DET} \propto V_{REF} = \alpha[I_{RESET} \cdot T - C_F \cdot (V_2 - V_1)]$$

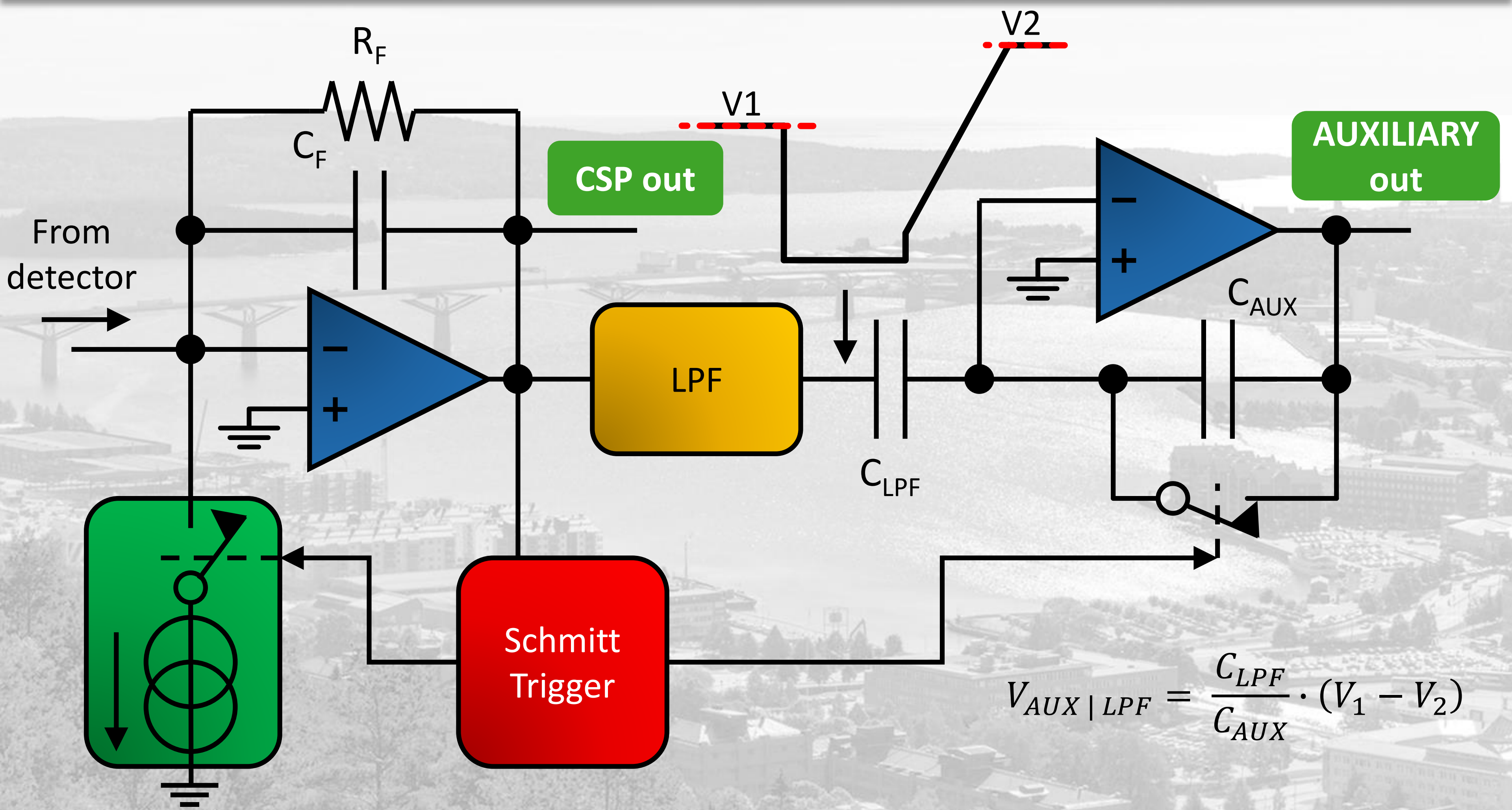


An algorithm to correct the spectra from the baseline dependency

$$V_{AUX\,|\,CG} = \frac{1}{C_{AUX}} \int_0^T I_{RESET}\, dt = \frac{I_{RESET} \cdot T}{C_{AUX}}$$



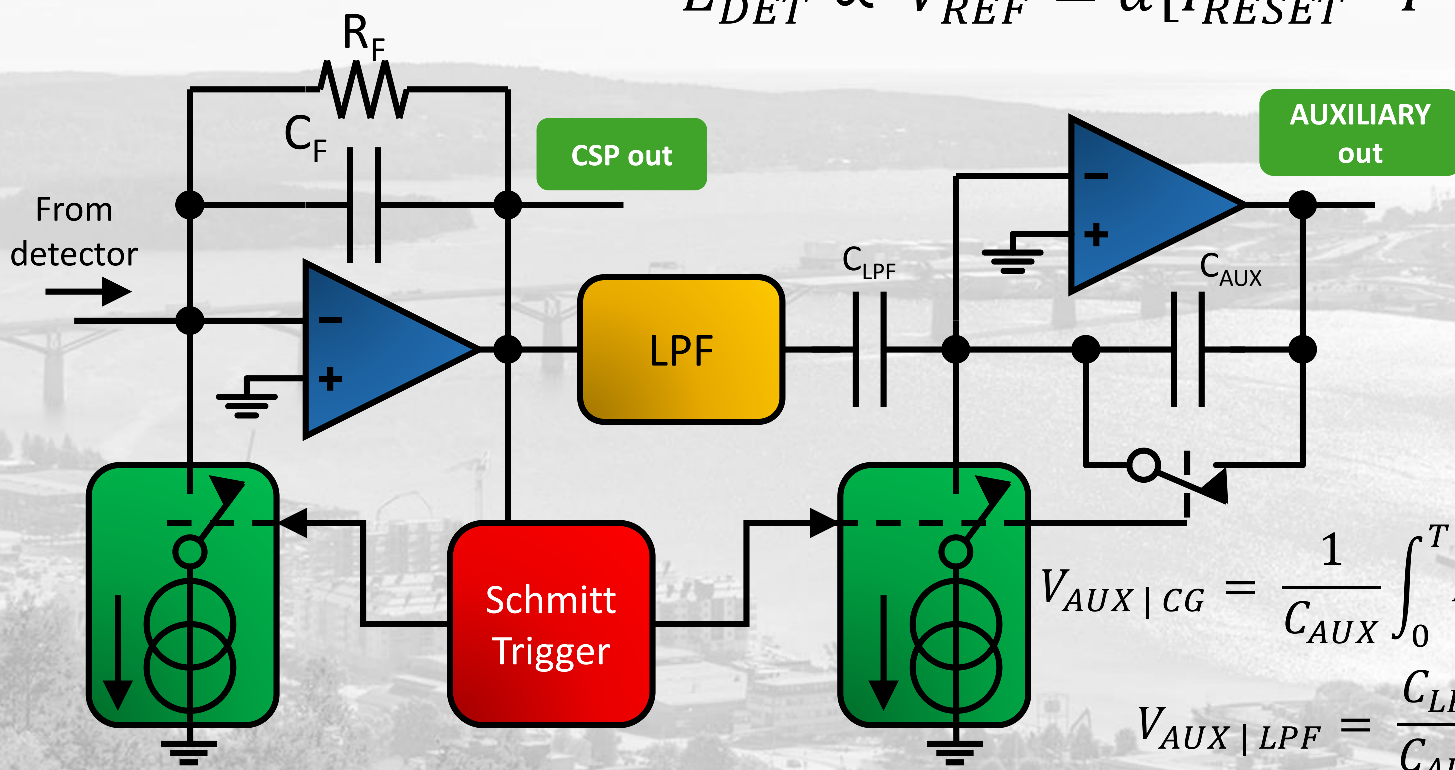
An algorithm to correct the spectra from the baseline dependency



$$V_{AUX\,|\,LPF} = \frac{C_{LPF}}{C_{AUX}} \cdot (V_1 - V_2)$$

An algorithm to correct the spectra from the baseline dependency

$$E_{DET} \propto V_{REF} = \alpha[I_{RESET} \cdot T - C_F \cdot (V_2 - V_1)]$$



$C_F = C_{LFP}$

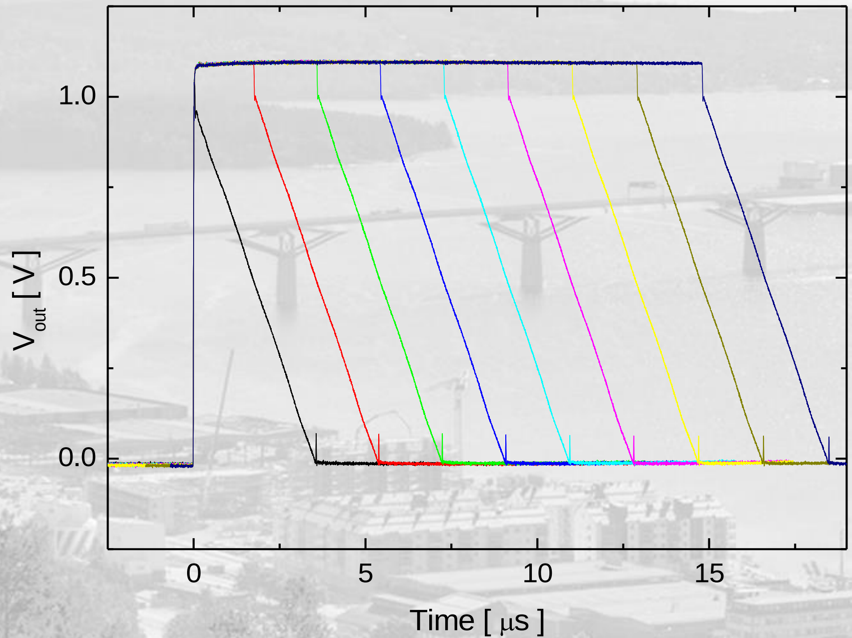
$$V_{AUX\,|\,CG} = \frac{1}{C_{AUX}} \int_0^T I_{RESET}\, dt = \frac{I_{RESET} \cdot T}{C_{AUX}}$$

$$V_{AUX\,|\,LPF} = \frac{C_{LPF}}{C_{AUX}} \cdot (V_1 - V_2)$$

$$V_{AUX} = \frac{1}{C_{AUX}} \cdot [I_{RESET} \cdot T - C_{LPF} \cdot (V_2 - V_1)]$$

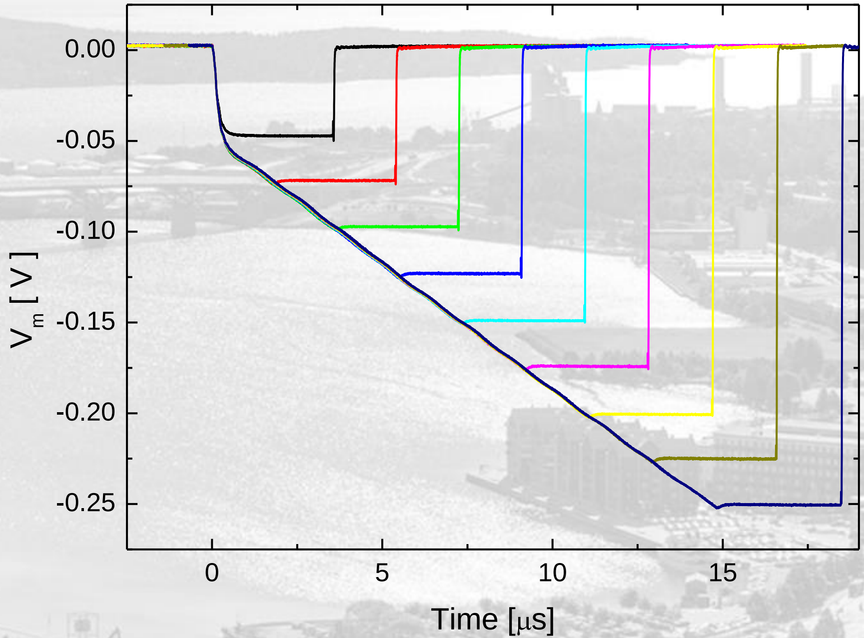
Experimental results: linearity test

CSP out



- 2 pC to 10 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor

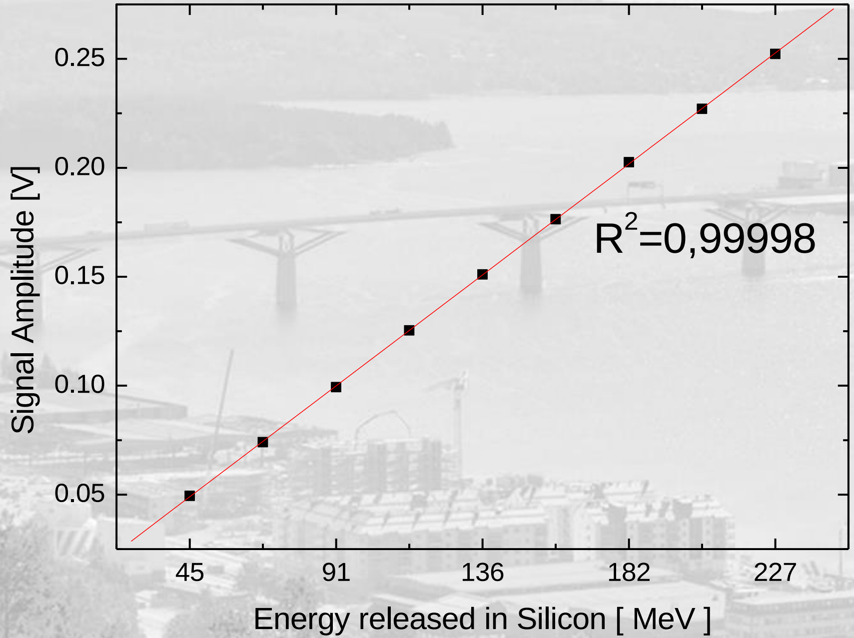
AUXILIARY out



- The auxiliary TAC structure produces signals that are linear in amplitude with the energy!

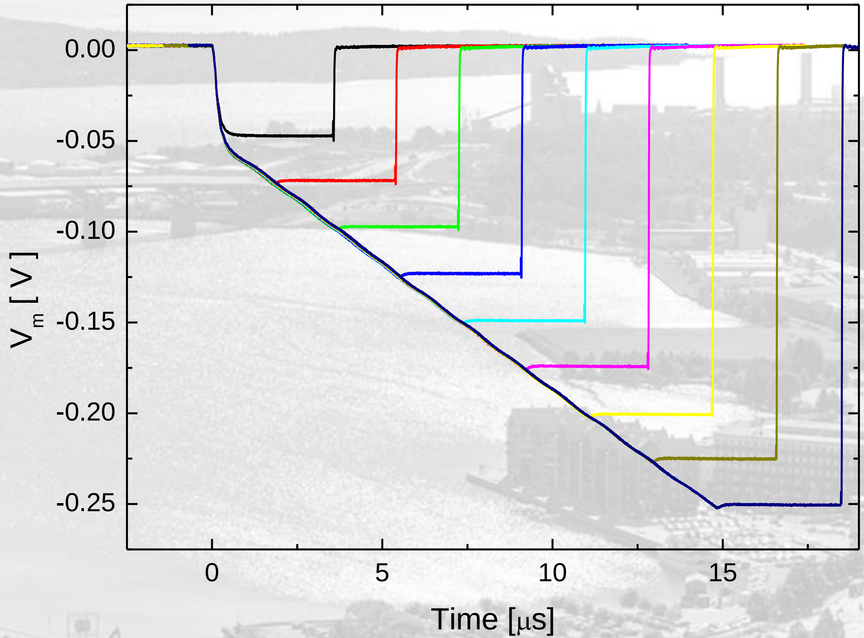
Experimental results: linearity test

Linear fit



- 2 pC to 10 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor

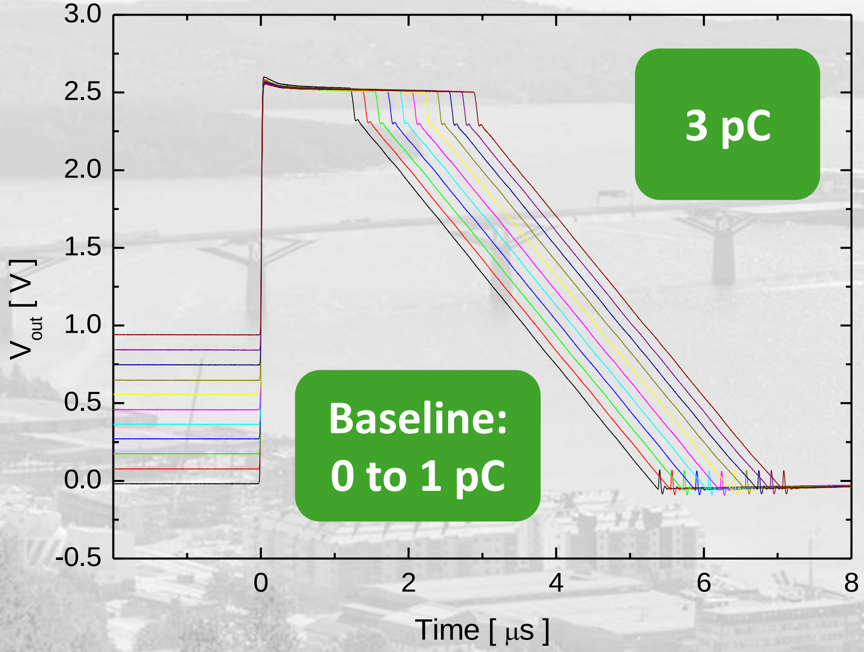
AUXILIARY out



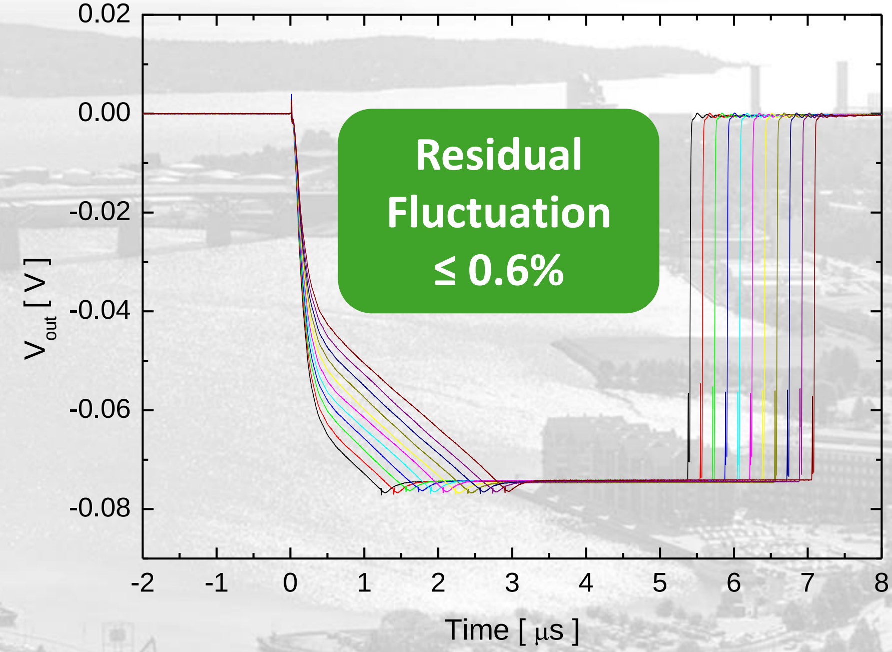
- The auxiliary TAC structure produces signals that are linear in amplitude with the energy!

Experimental results: baseline rejection

CSP out



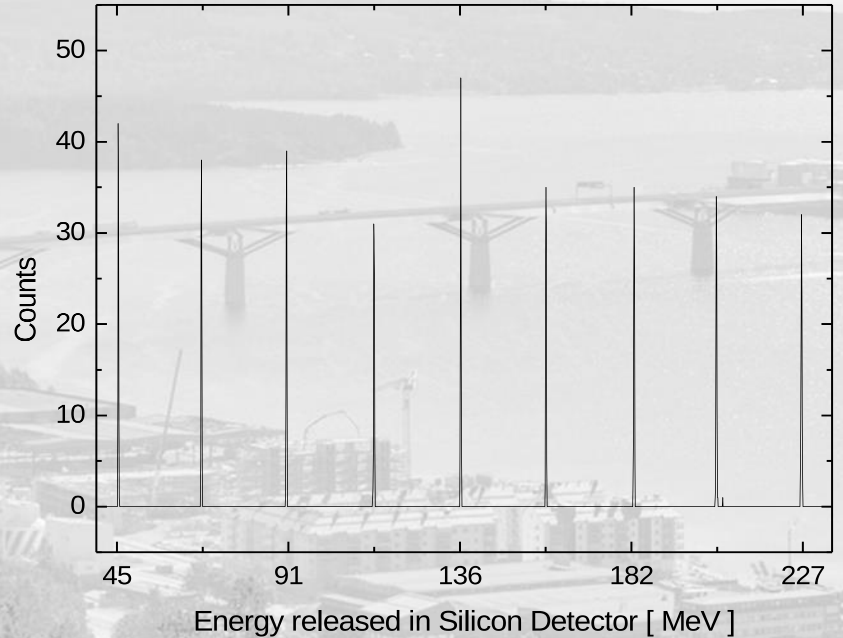
AUXILIARY out



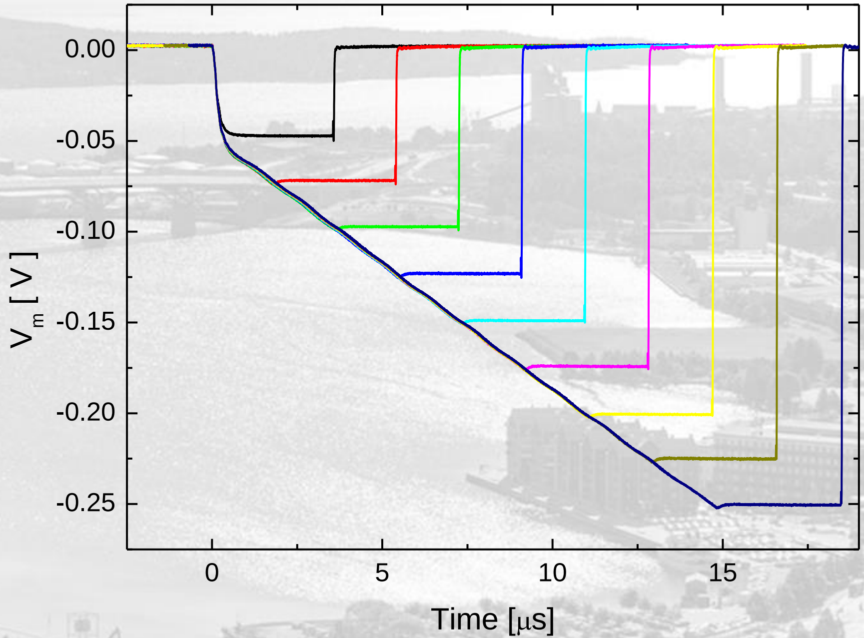
- 3 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor. From 0 to 1pC of residual charge on the input node
- The auxiliary TAC structure produces signals that change in shape but keep the same amplitude!

Experimental results: Resolution

Amplitude histogram



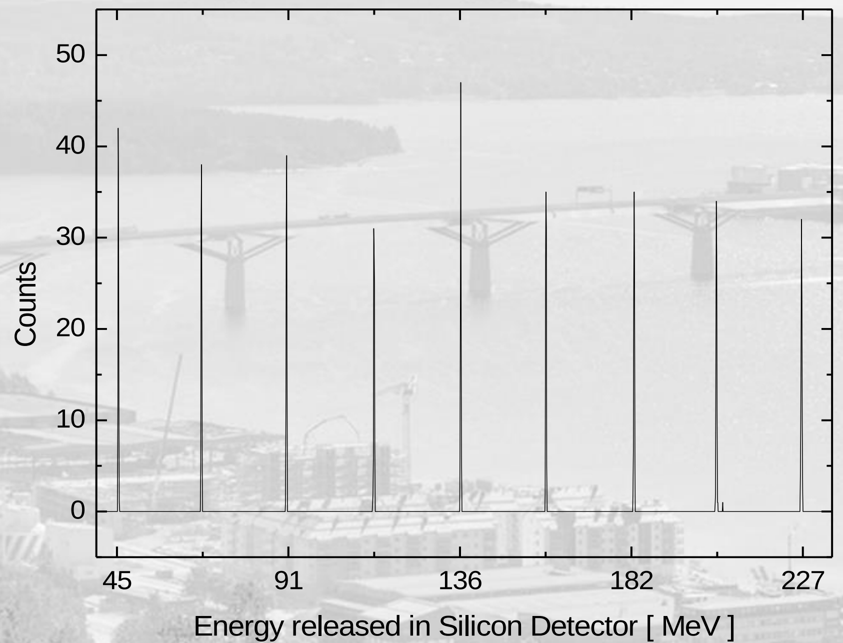
AUXILIARY out



- 2 pC to 10 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor. 100 signals acquired for each peak

Experimental results: Resolution

Amplitude histogram



Peak resolutions

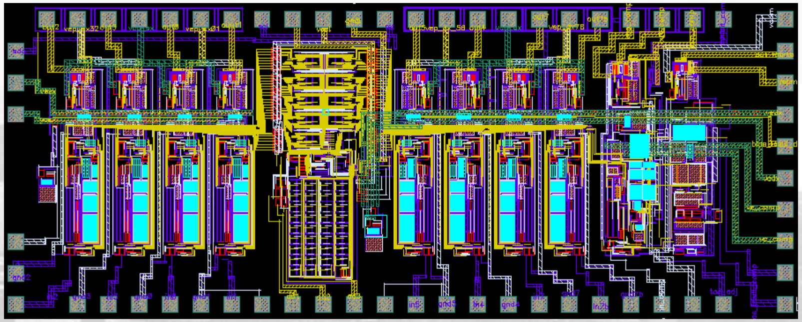
Input Charge [pC]	Signal amplitude [mV]	Peak width FWHM [mV]	Peak width FWHM [%]
2	49.394	0.210	0.43
3	74.073	0.243	0.33
4	99.329	0.229	0.23
5	125.33	0.296	0.24
6	151.08	0.247	0.16
7	176.39	0.227	0.13
8	202.56	0.269	0.13
9	227.03	0.291	0.13
10	252.27	0.347	0.14

- 2 pC to 10 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor. 100 signals acquired for each peak

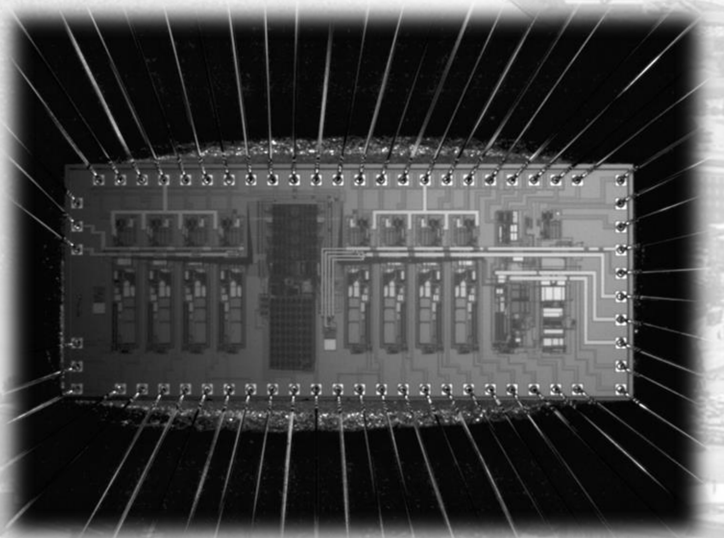
BEST-CASE RESOLUTION OF 0.13% FWHM OF THE TOTAL ENEGY!

Conclusions

- A low-noise low-power CSP ASIC was presented with an innovative range-booster circuit
- The CSP meets the requirements of gamma spectroscopy (but also suitable for particle spectroscopy)
- The fast risetime enables to process the signals from this preamplifier with pulse-shape analysis algorithms

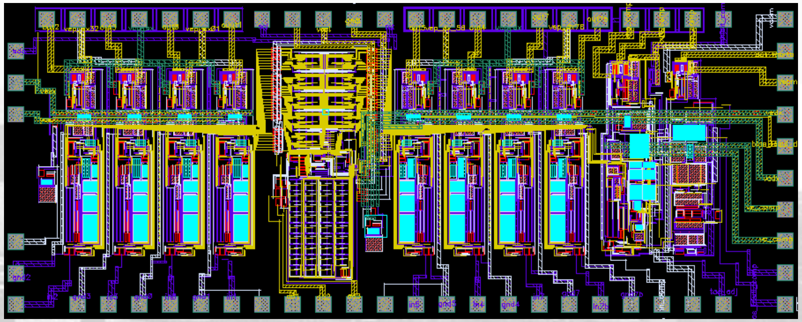


- An innovative technique was presented that extends the natural dynamic range of the preamplifier from 40 MeV to several hundreds of MeV
- The TTA algorithm was implemented in an analog circuit that performs the operation on-line and is not influenced by the signal's baseline

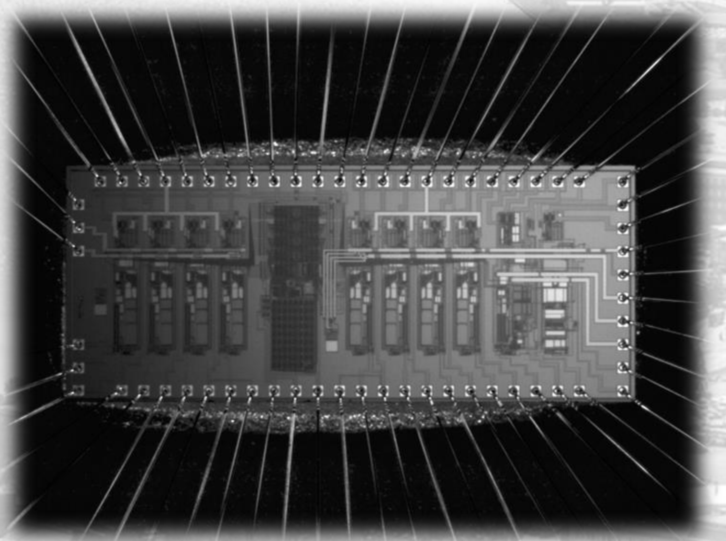


Perspectives

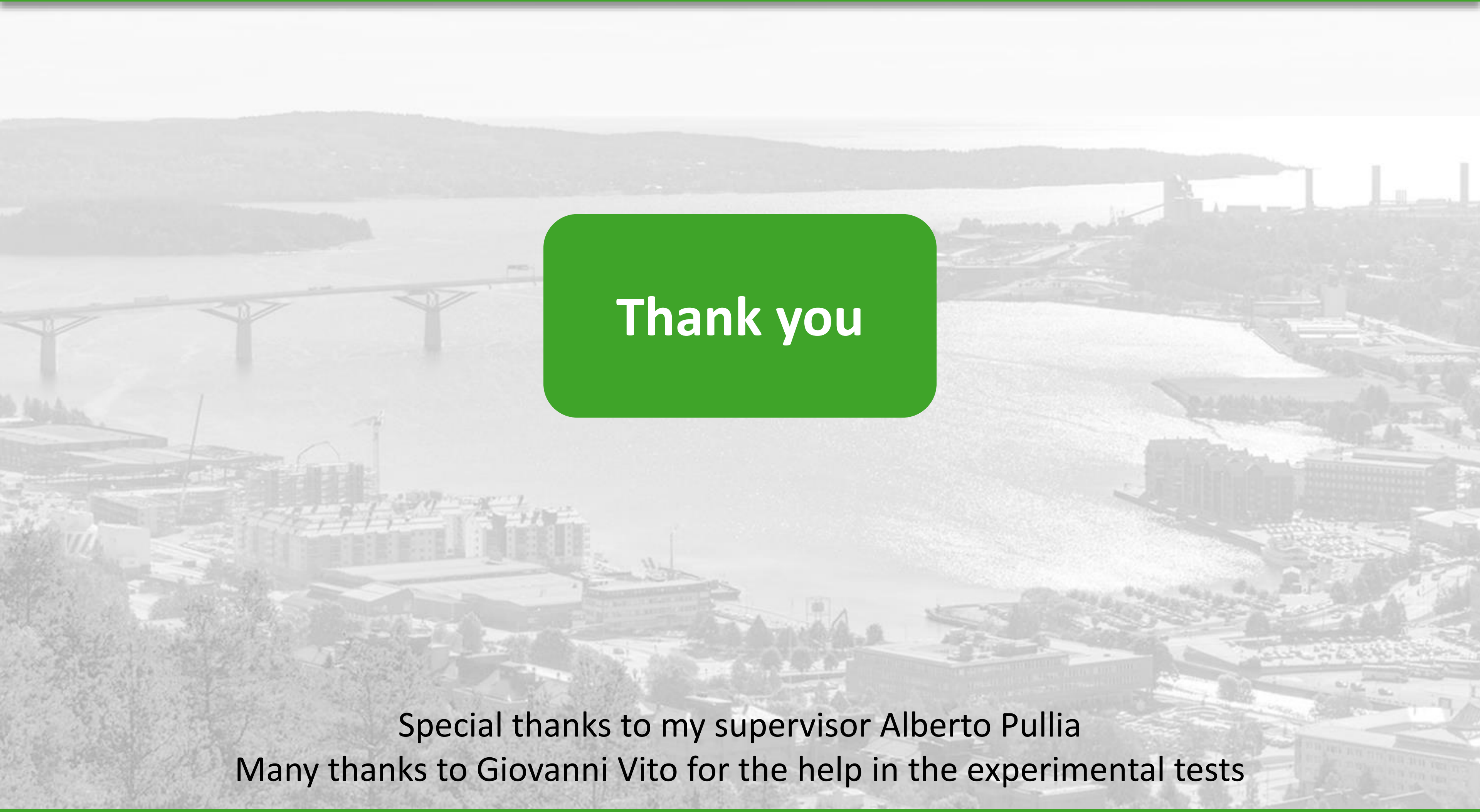
New ASIC preamplifier for signals with opposite polarities already submitted to the foundry



Extended tests on the chip (higher pulser energies, test with actual detector and cryogenic operation)



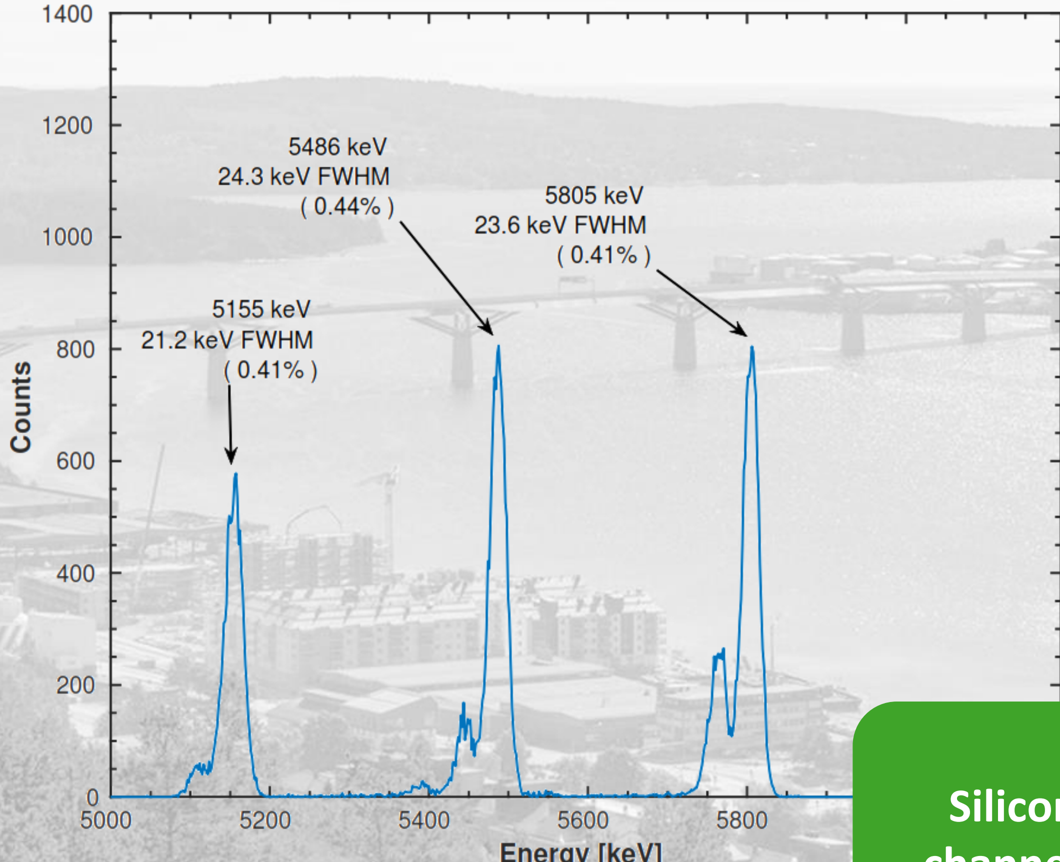
Finalization before end 2018 of the first TRACE detector array

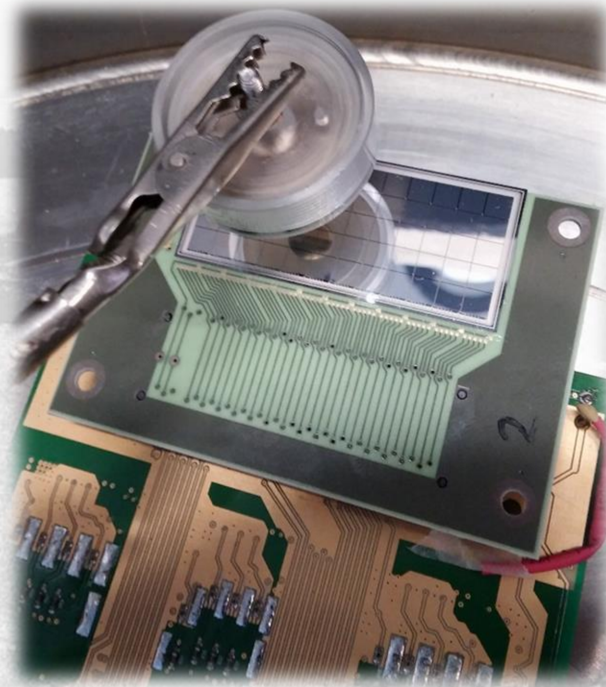


Thank you

Special thanks to my supervisor Alberto Pullia
Many thanks to Giovanni Vito for the help in the experimental tests

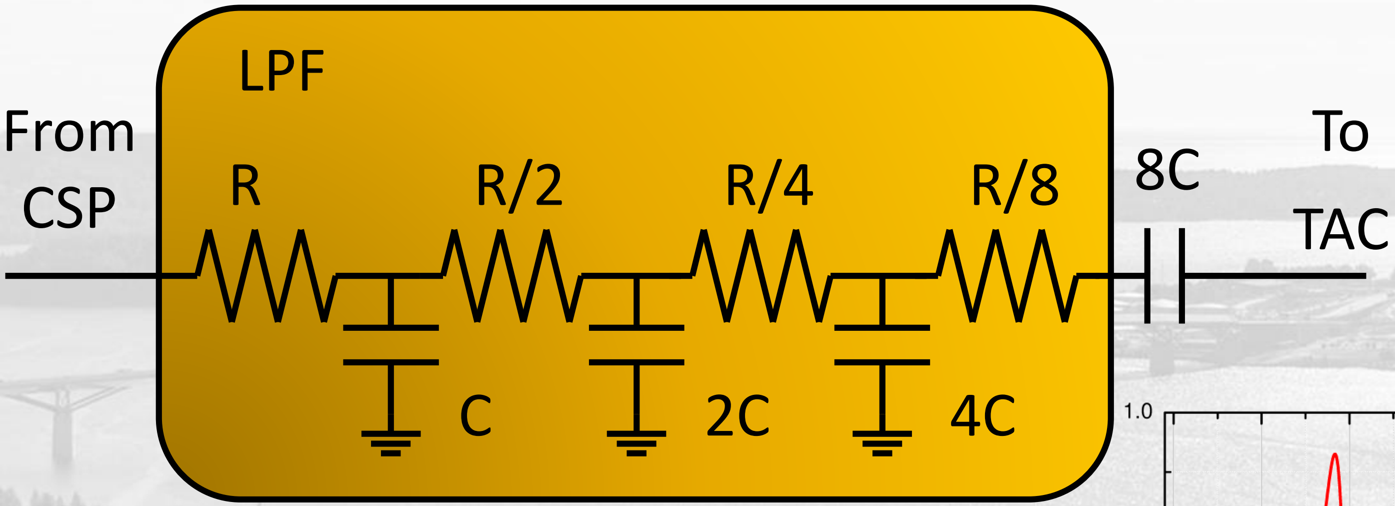
Experimental tests with detector (previous chip version)

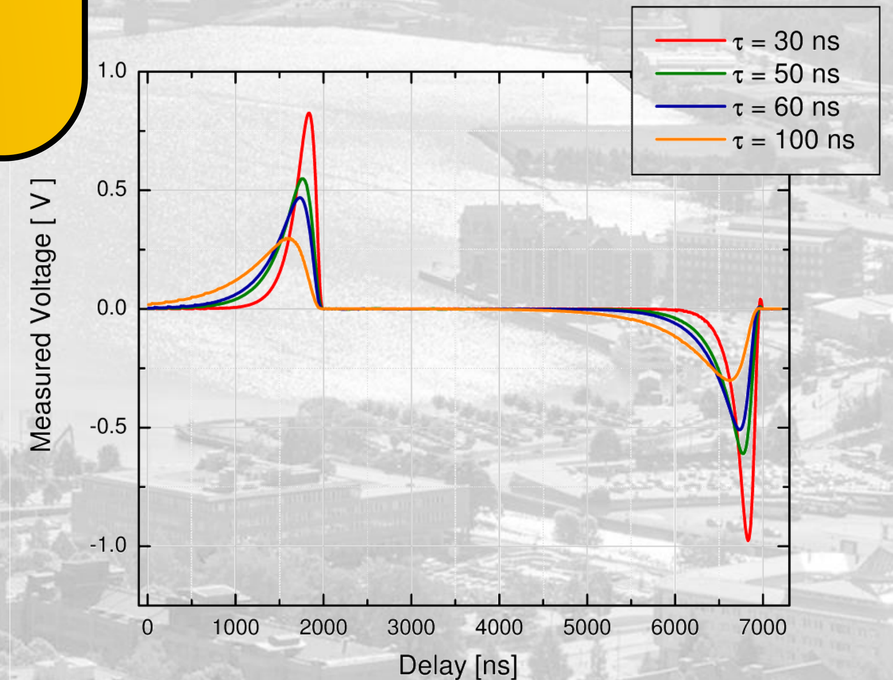




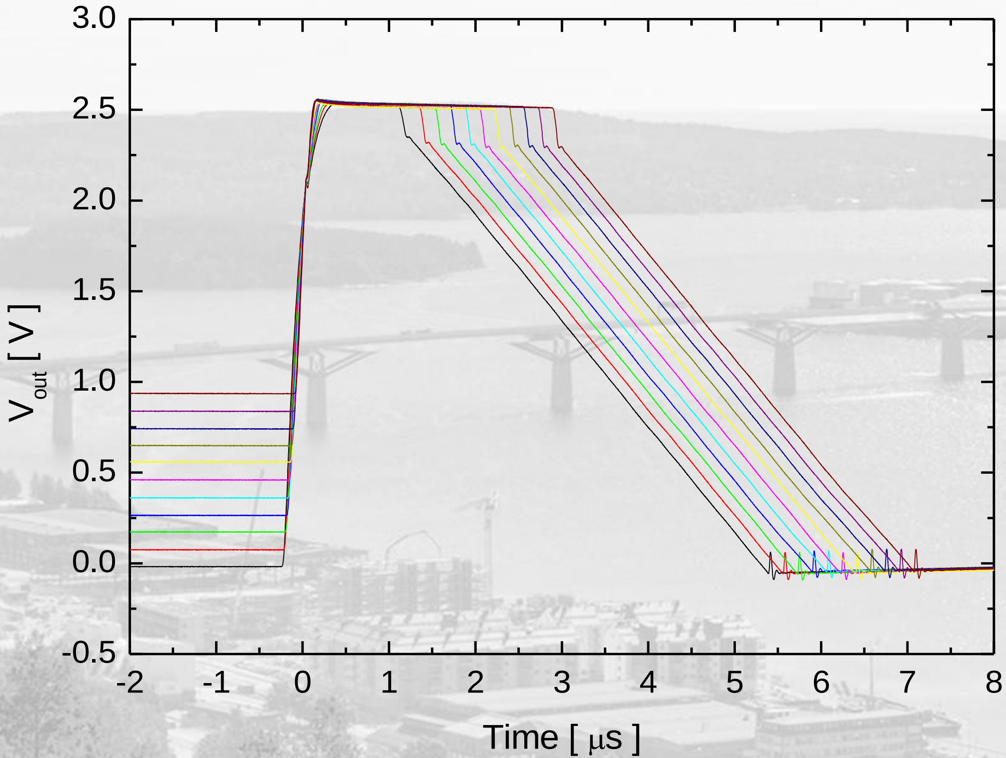
Silicon detector 1 mm thick, 32 active channels, Am-Cu-Pu mixed alpha source

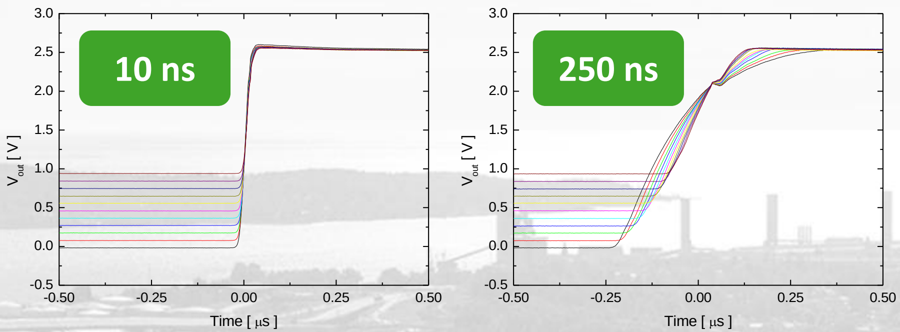
Low-pass filter

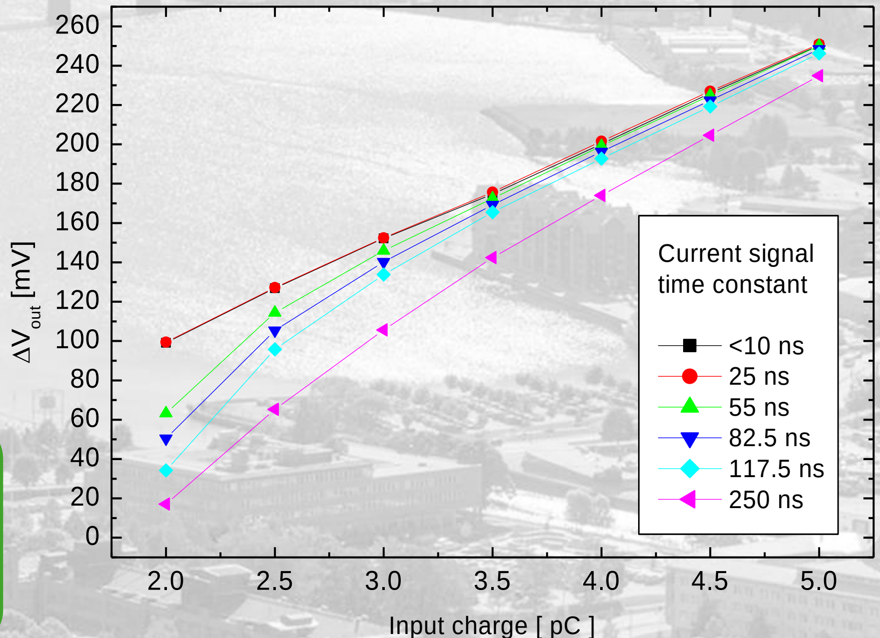




Limits of the algorithm







A signal risetime with time constant comparable to the one of the LPF (or higher) induces some errors in the rejection algorithm