Active Stoppers for Decay Experiments

Valencia, Spain, March 24-26 2025

Organizing Committee:

Anabel Morales (IFIC, CSIC-UV)
Tom Davinson (U. Edinburgh)
Andrés Gadea (IFIC, CSIC-UV)
Nic Hubbard (GSI)
Shunji Nishimura (RIKEN)
Marta Polettini (GSI)
Jelena Vesic (IJS)

ADVANCES IN INTEGRATED FRONT-END CIRCUITS FOR SEMICONDUCTOR DETECTORS

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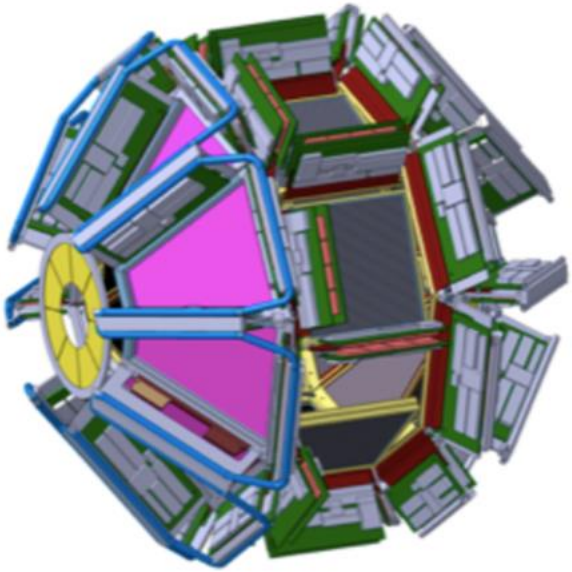
Dept. Of Physics, University of Milano, Milano, Italy
INFN of Milano, Milano, Italy

Research background

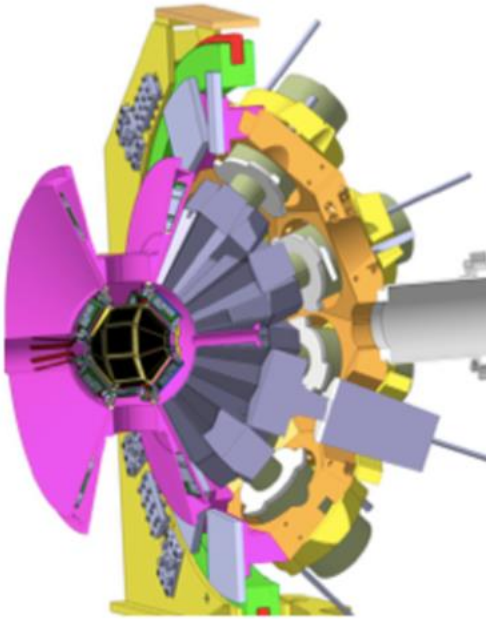
My background: integrated electronics for Particle spectroscopy with silicon detectors for research in nuclear physics

The goal: perform particle spectroscopy down to 0.5 MeV but also up to some hundreds of MeV

GRIT ARRAY



GRIT AND AGATA



0.5 MeV — 500 MeV

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Hybrid readout techniques

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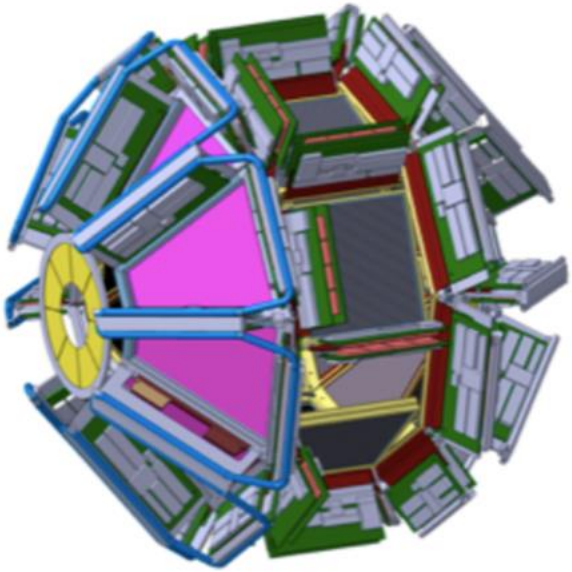

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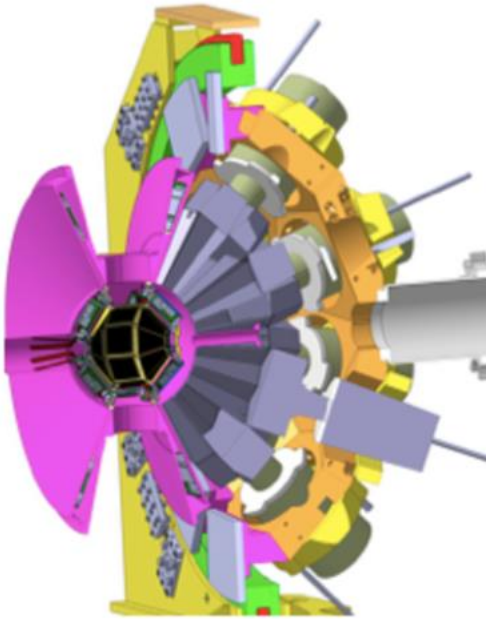

0.5 MeV — Comfort zone — 600 MeV

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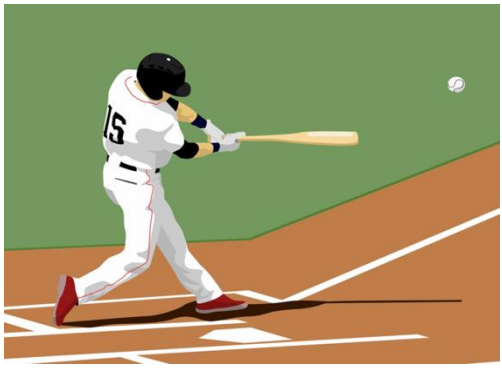
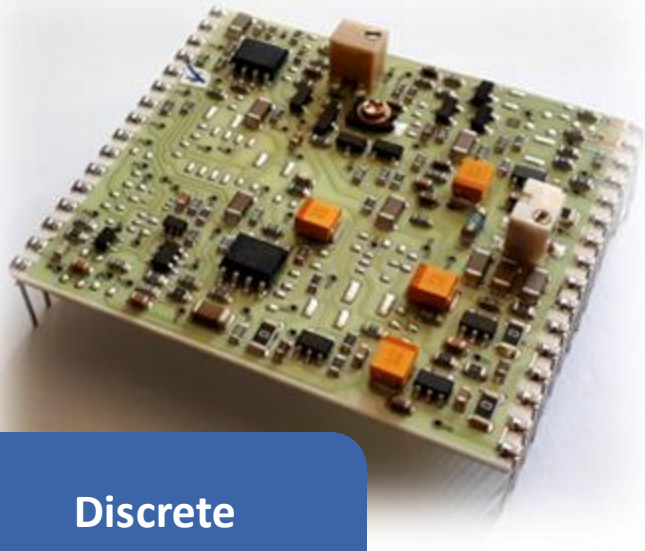


Tens of keV (beta) — 0.5 MeV — 500 MeV — Several GeV (HI-implant)

From discrete circuits to integrated ones

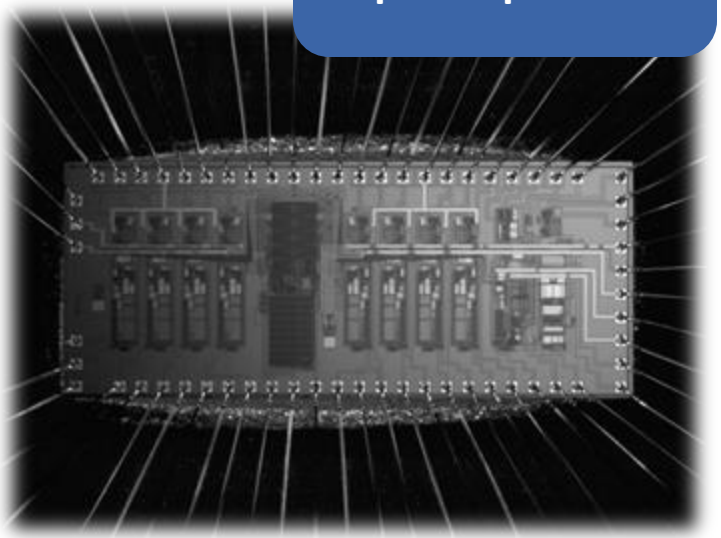


Discrete preamplifiers

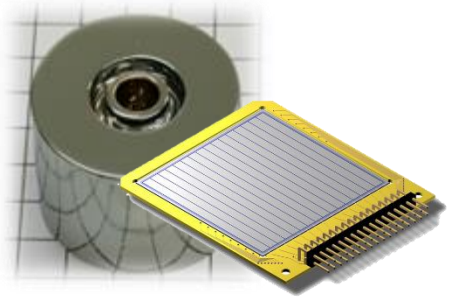
- Not suitable in case of high channel density
- Components tolerant to higher bias voltages -> High dynamic range
- Higher power consumption
- Design flexibility

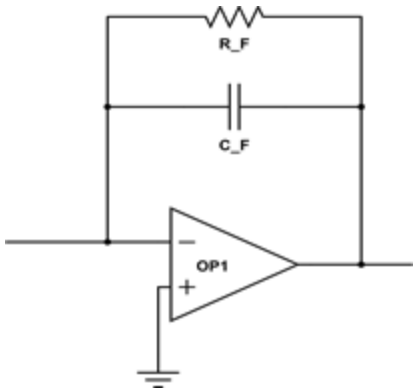
- Suitable in case of high channel density
- Components tolerant to lower bias voltages -> Low dynamic range
- Low power consumption
- Radio-purity

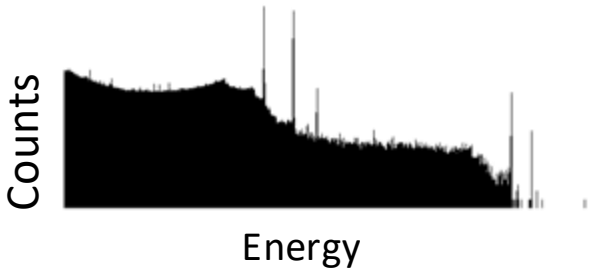
Integrated preamplifiers



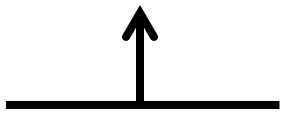
Spectroscopic Chain

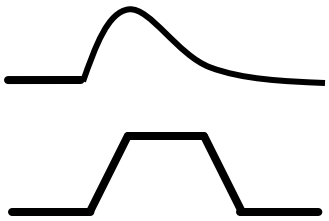






Solid-state detector → **Charge-Sensitive Preamplifier** → **Amplifier and MCA or ADC with digital filtering**

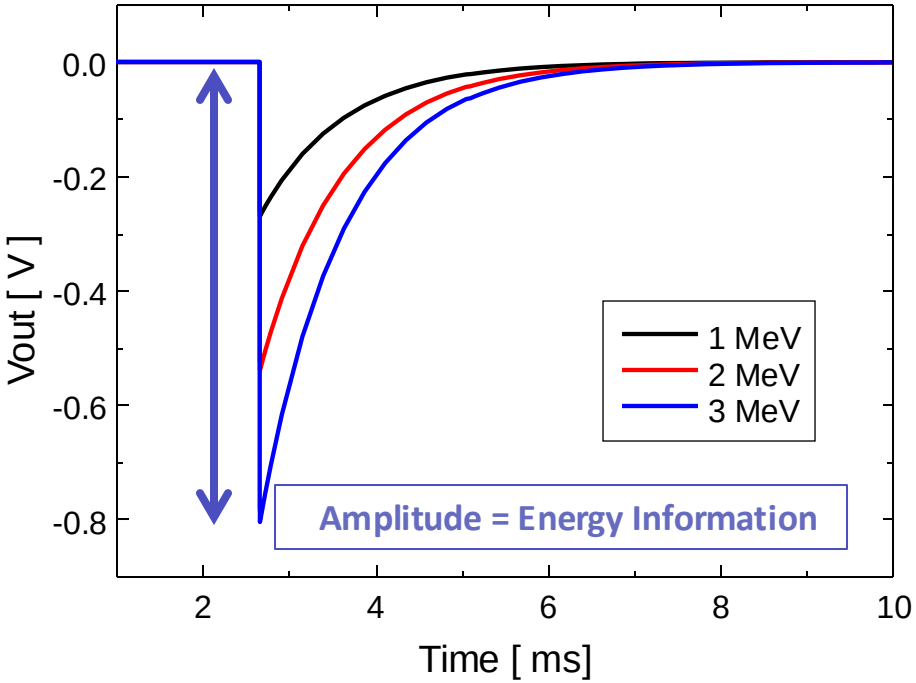




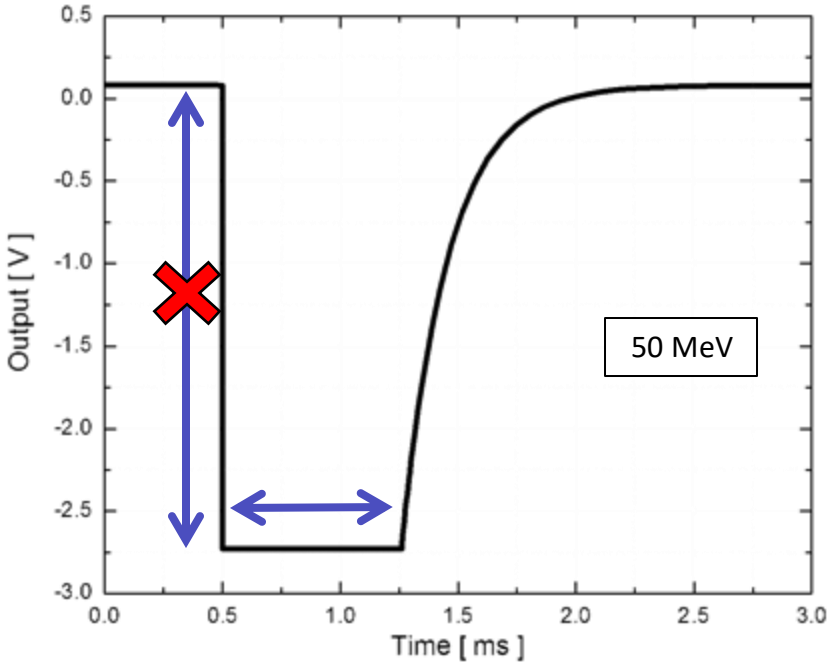
$$i(t) = Q \cdot \delta(t)$$

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

Effects of the saturation on the signal shape of a CSP

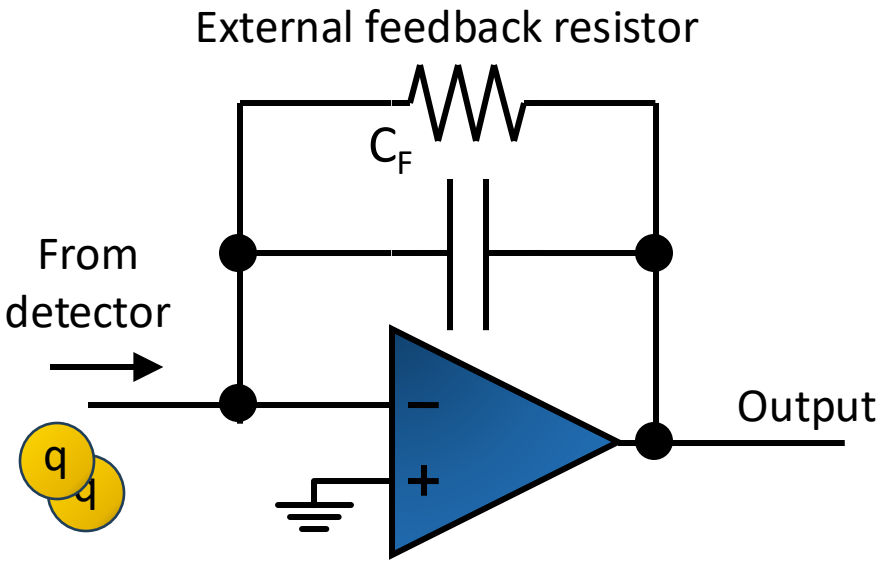


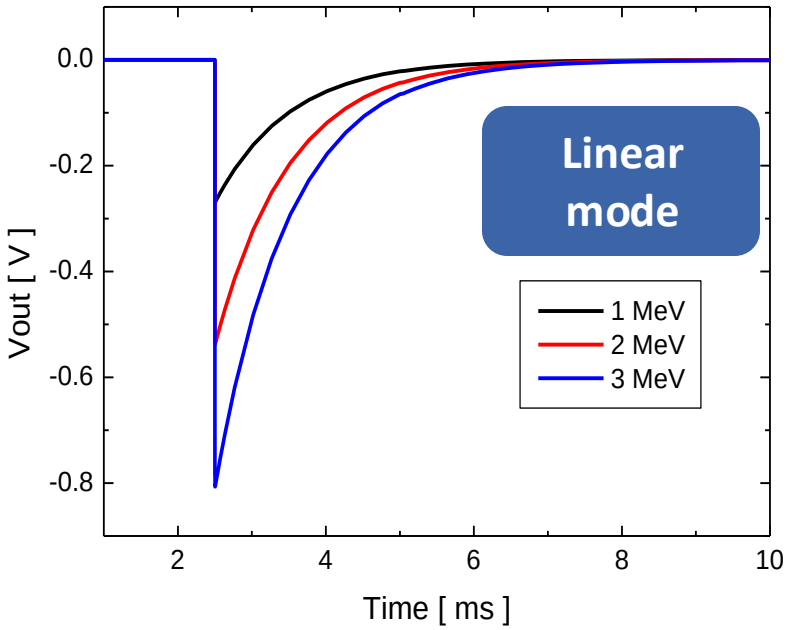
- Signal amplitude proportional to the energy deposited in the detector
- Decay constant determined by the RC product of the CSP



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

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

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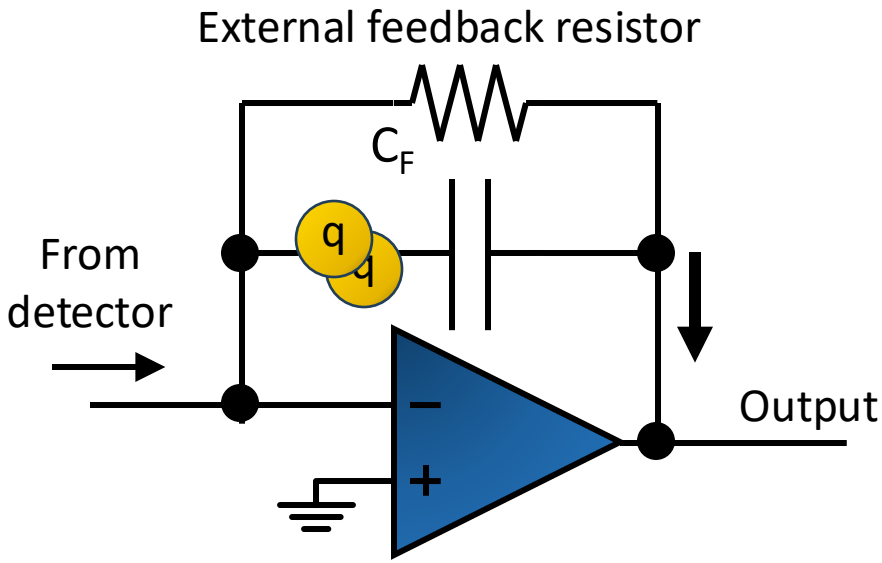

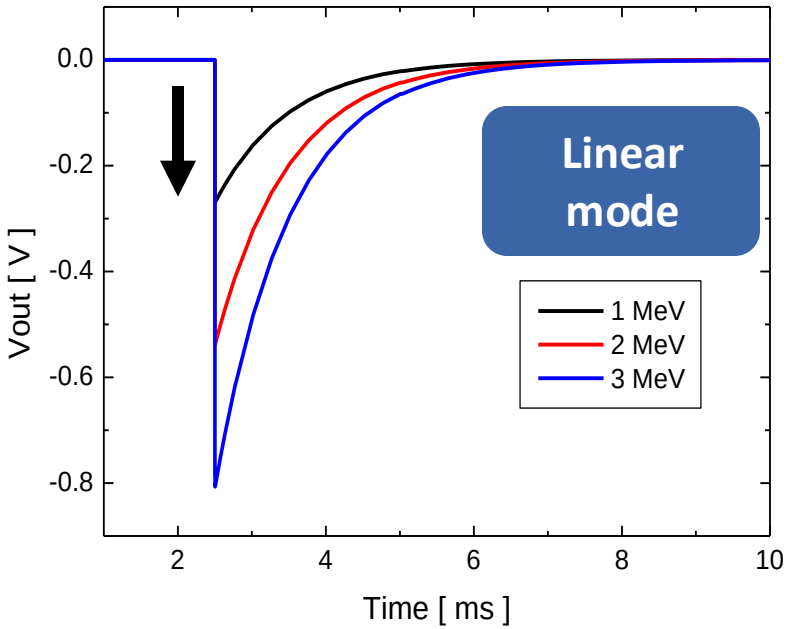

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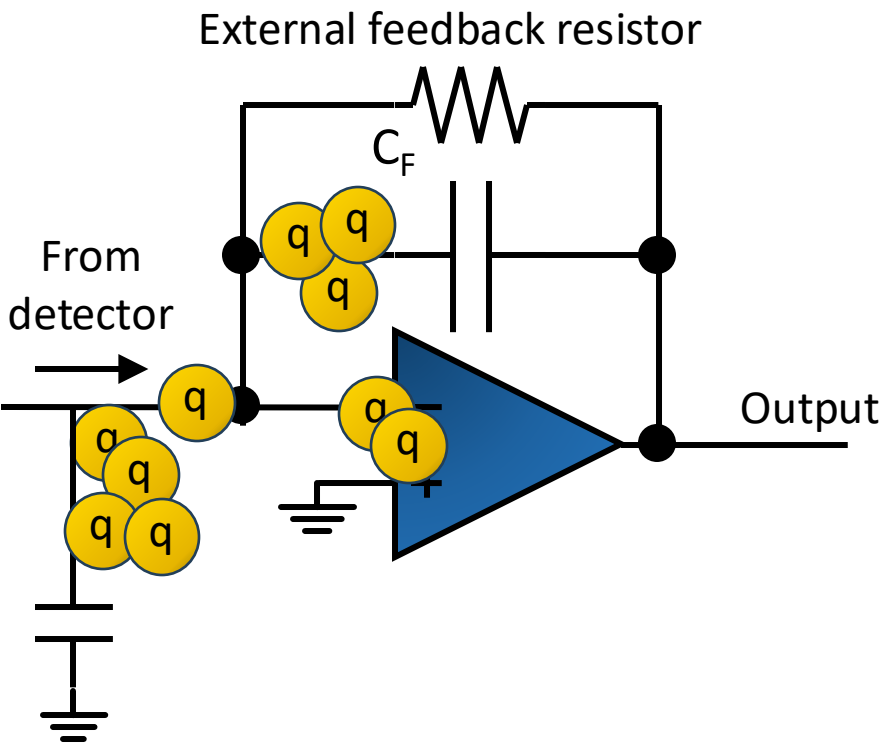

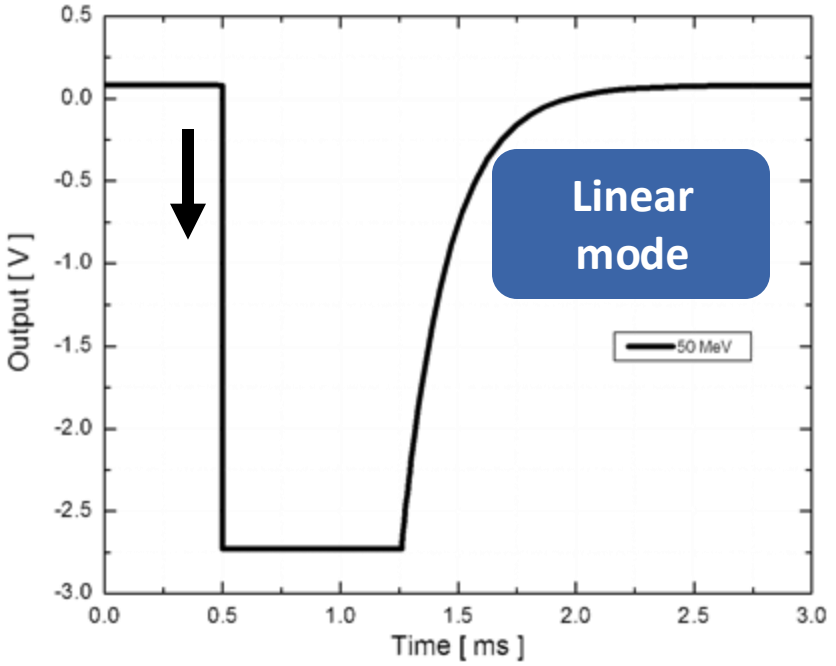

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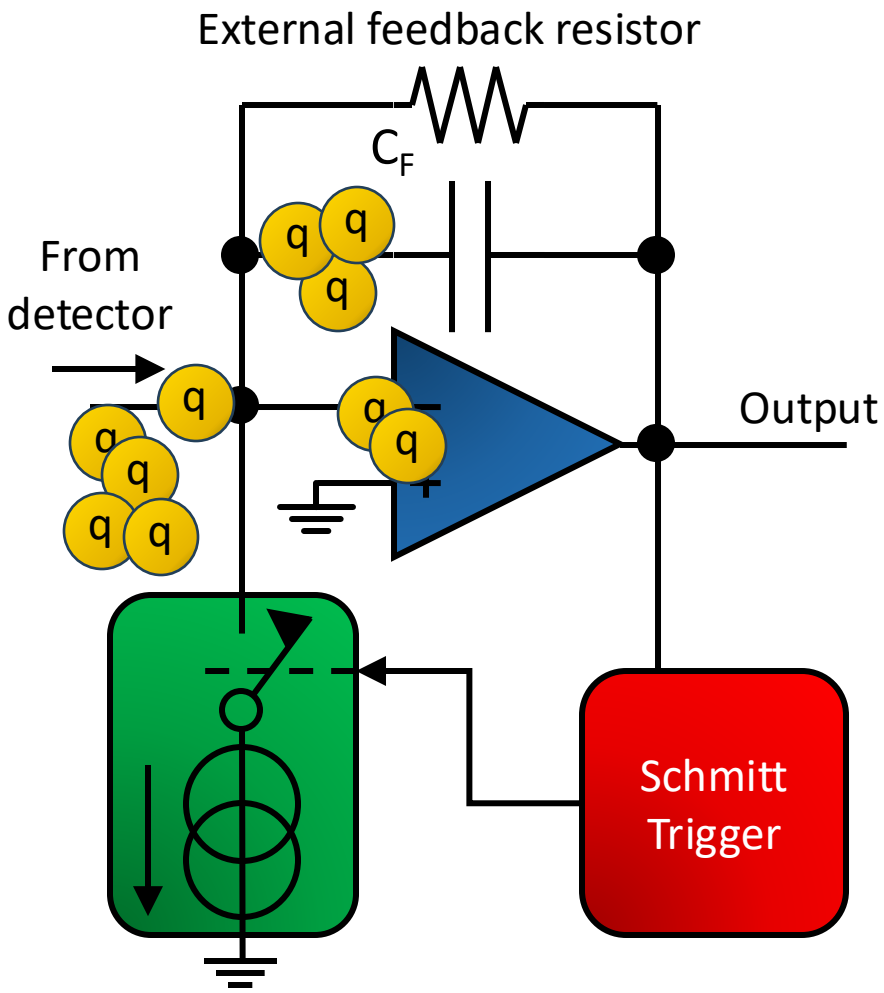

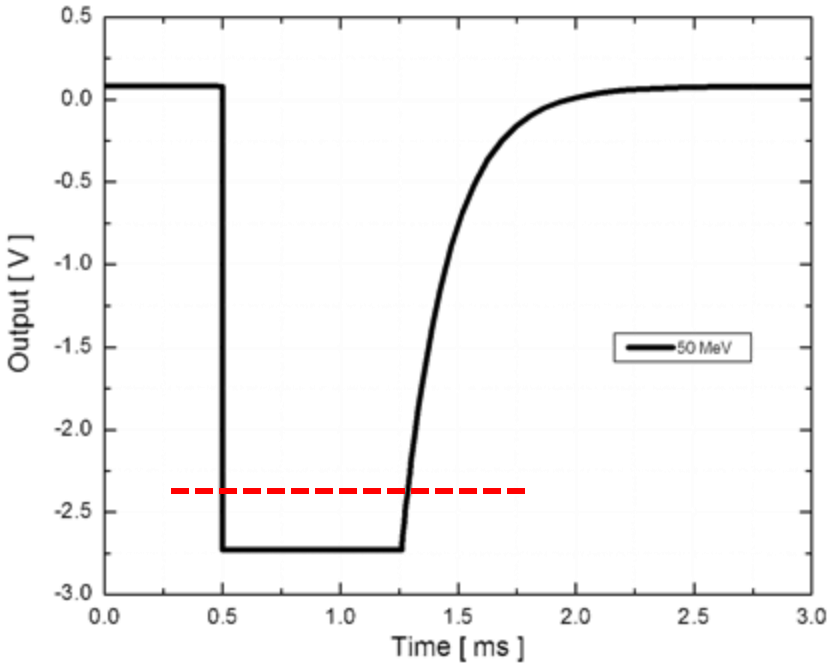

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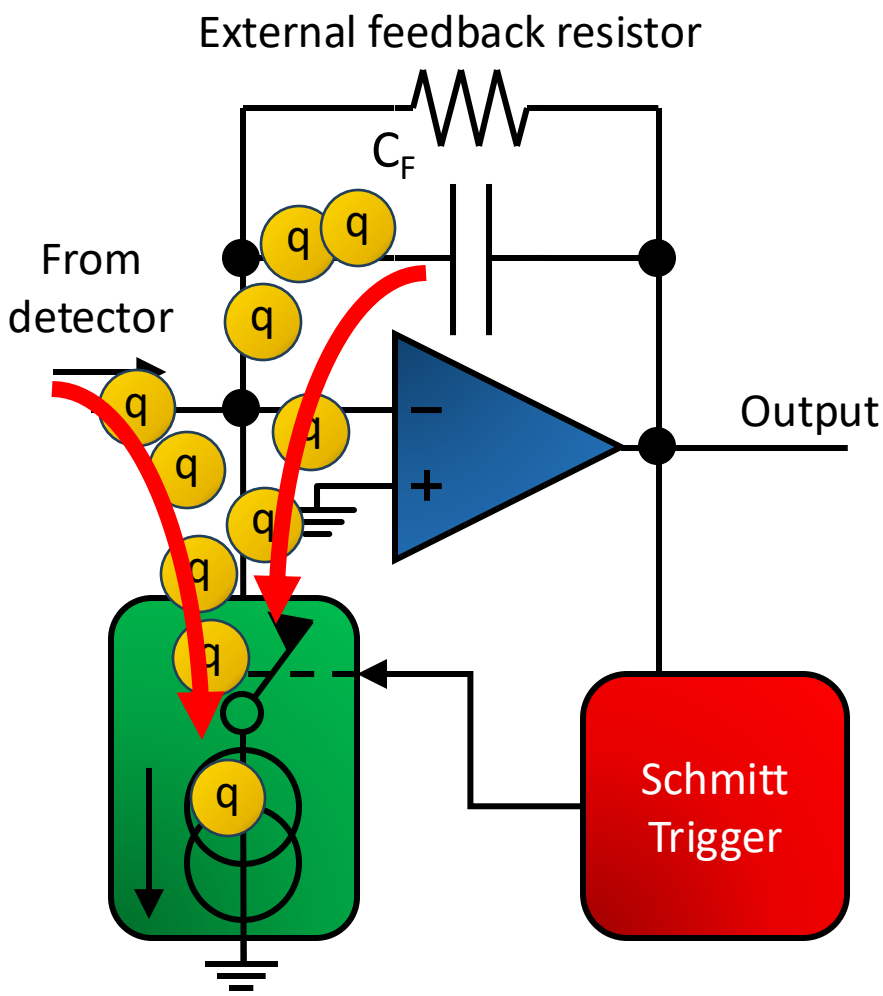

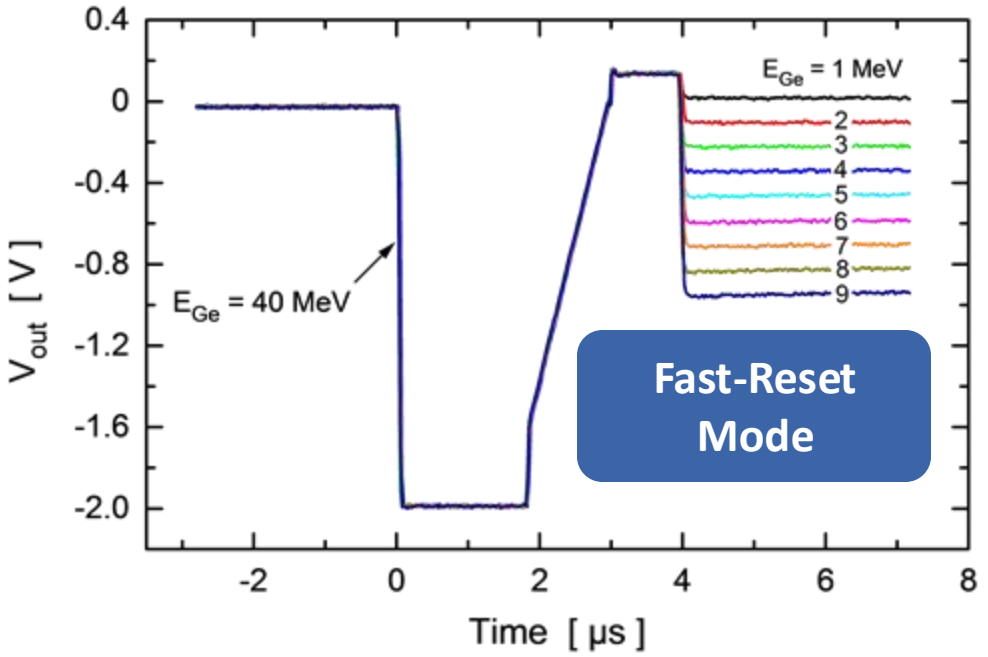

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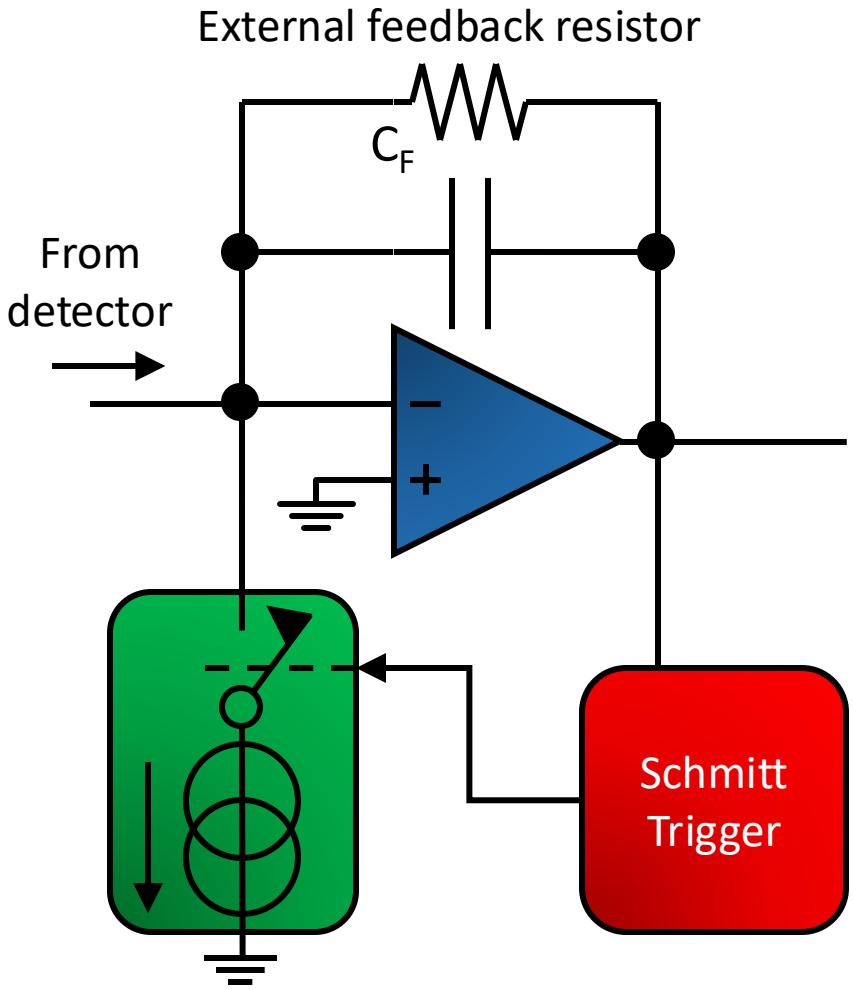
The Fast-Reset mode: Not only dead-time reduction But also High-resolution Spectroscopy



Charge-conservation principle

Constant and controlled Current generator

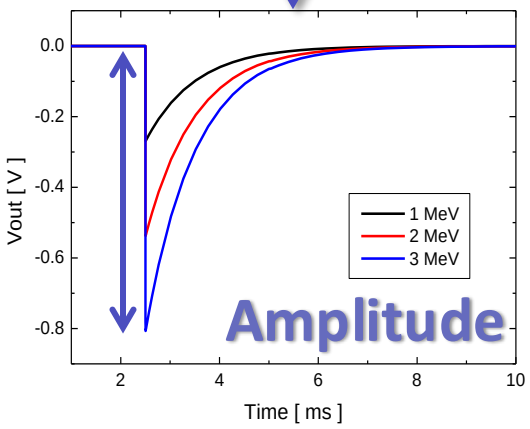
High-resolution spectroscopy with Time-over-Threshold algorithm

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

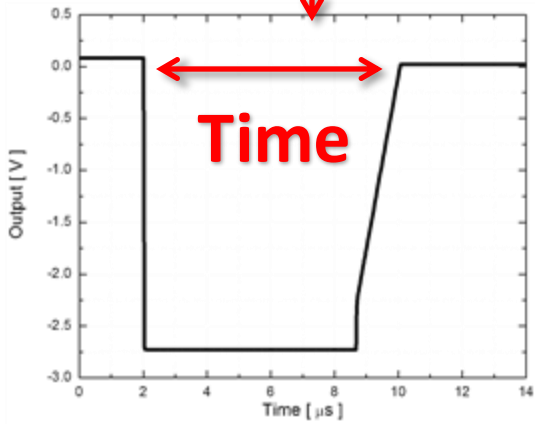
The Fast-Reset mode: Not only dead-time reduction But also High-resolution Spectroscopy

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

Energies under the saturation threshold
< 10 MeV

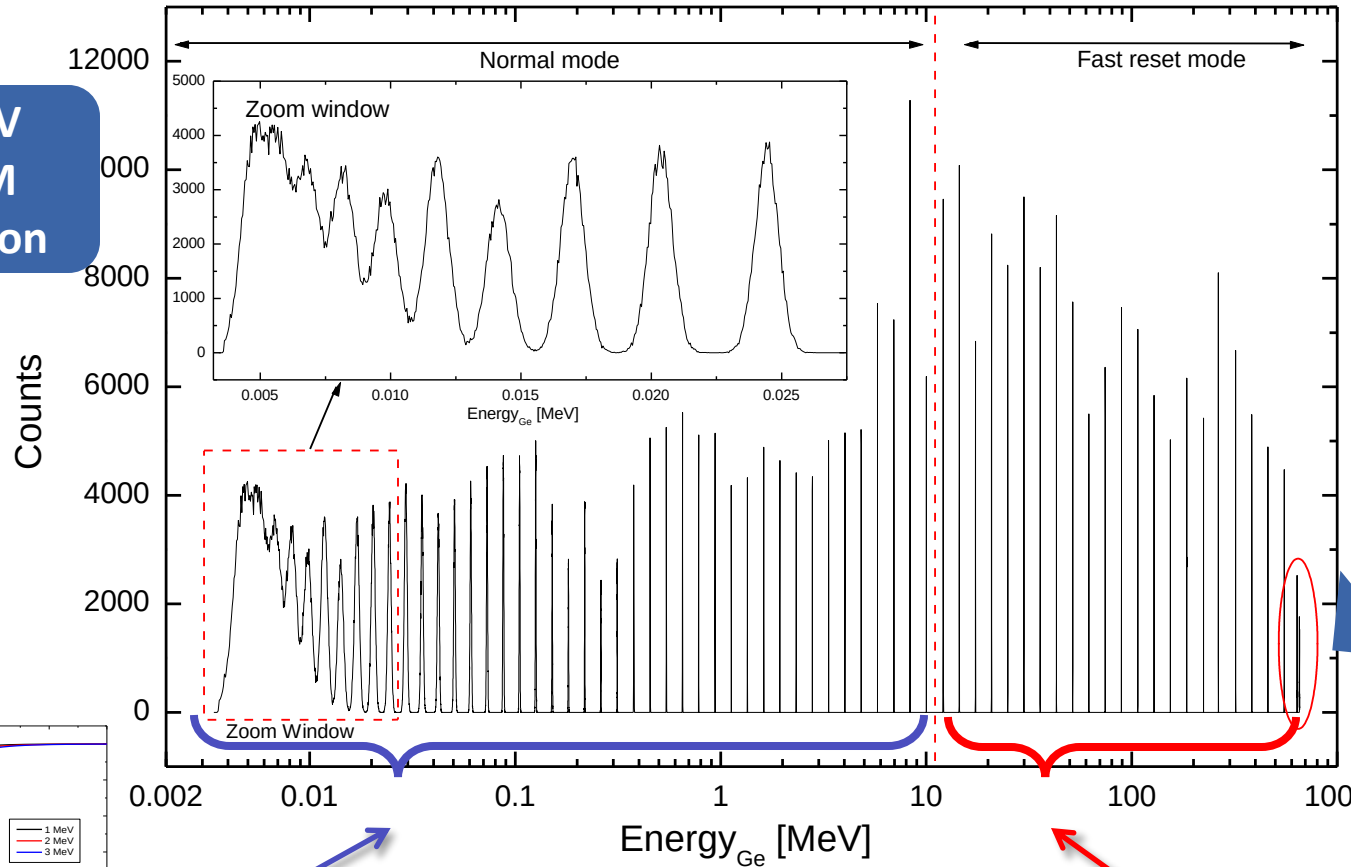


Energies over the saturation threshold
> 10 MeV

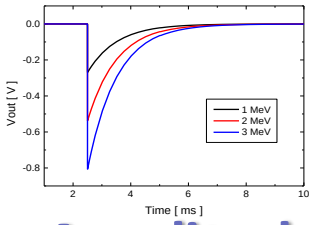


The Fast-Reset mode: Not only dead-time reduction But also High-resolution Spectroscopy

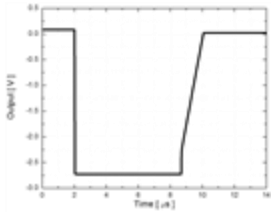
1.1 keV FWHM resolution



How can a saturated preamp saturate?



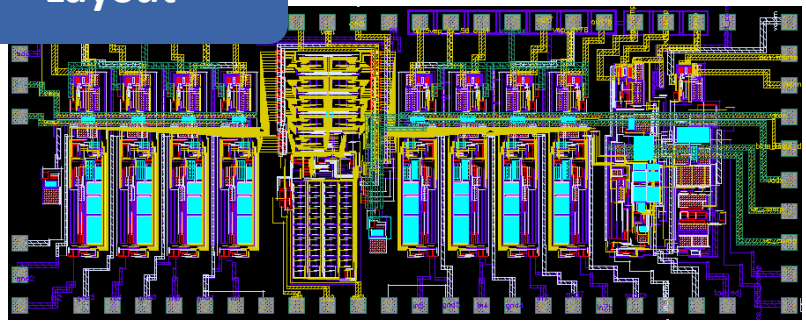
Amplitude



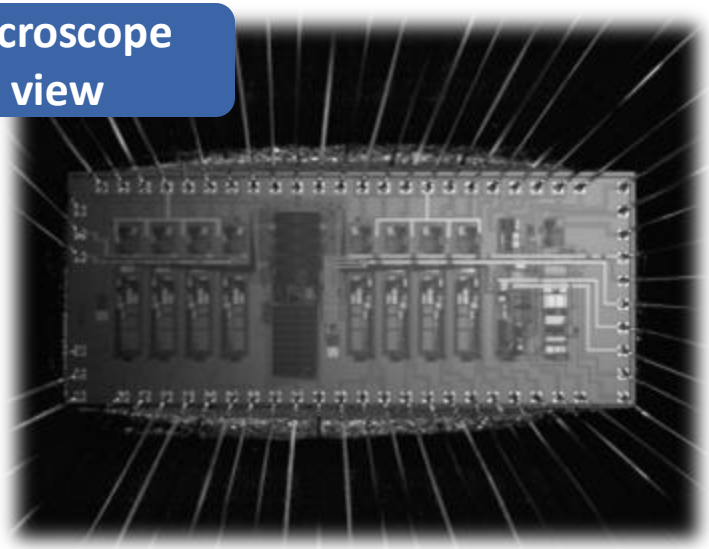
Time to Amplitude

The Fast-Reset Integrated preamplifier

Layout



Microscope view

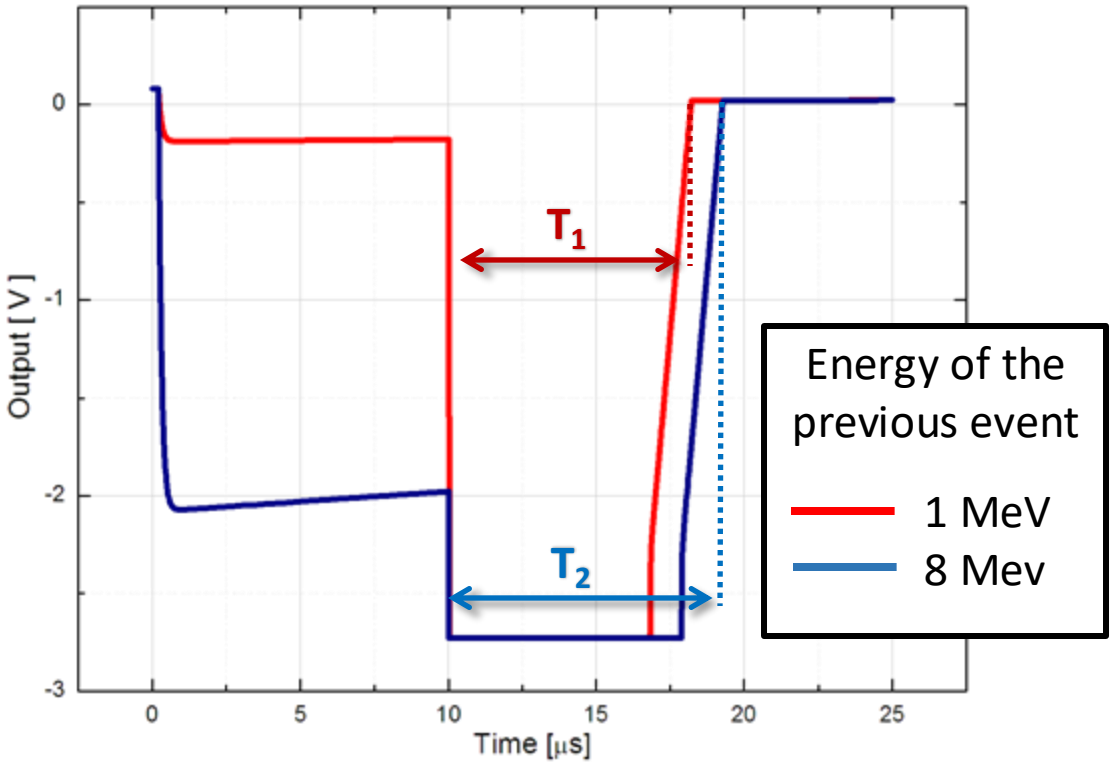


- Realized in AMS C35 technology
- 8 channels for anodic signals and 1 channel for cathodic ones
- Power consumption: 12 mW/ch
- Risetime: 10 ns (4 pF det. And 1 pF FB)
- Power supply: ±2.5V
- Area = 10mm^2

- Carrier: PLCC68 or bare die
- 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

Dependency of the energy measurement from the baseline value

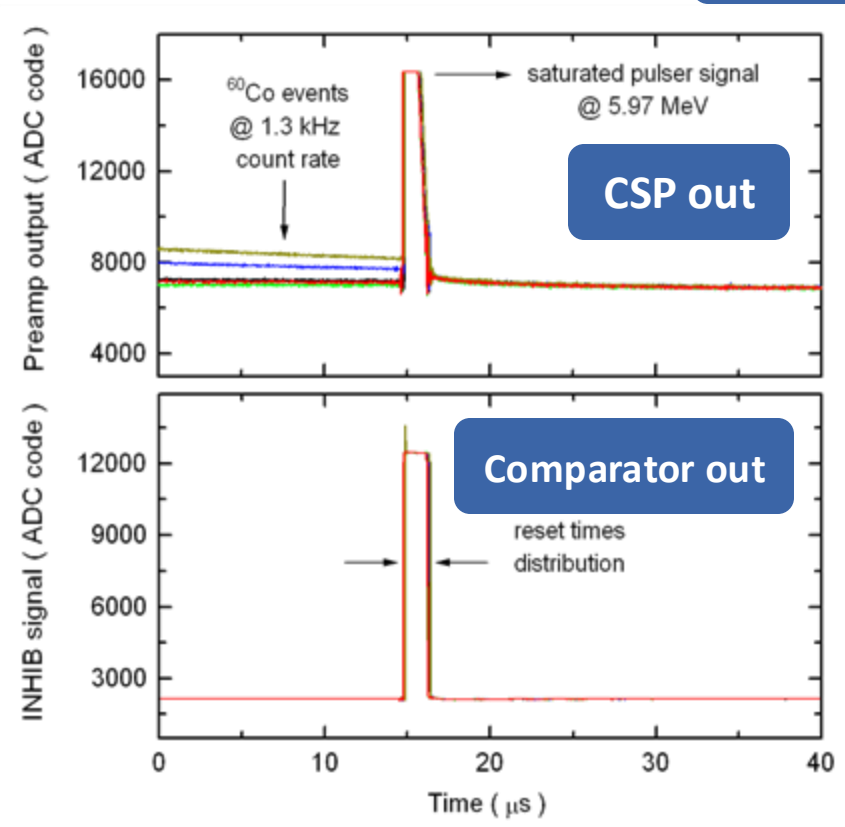
- The digital TOT signal depends on the residual charge on C_F before the reset process
- **Need for an algorithm to correct this dependency**
- Off-line digital correction: easy to implement but expensive in computational terms

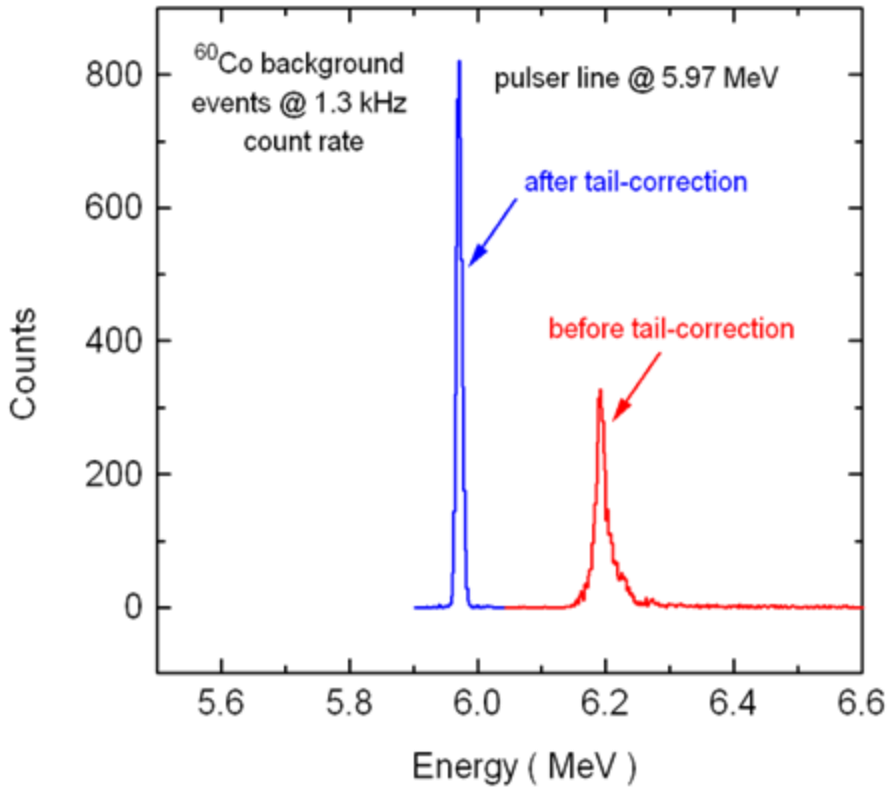


Dependency of the energy measurement from the baseline value

Pile-up effects at medium counting rate

1.3 KHz

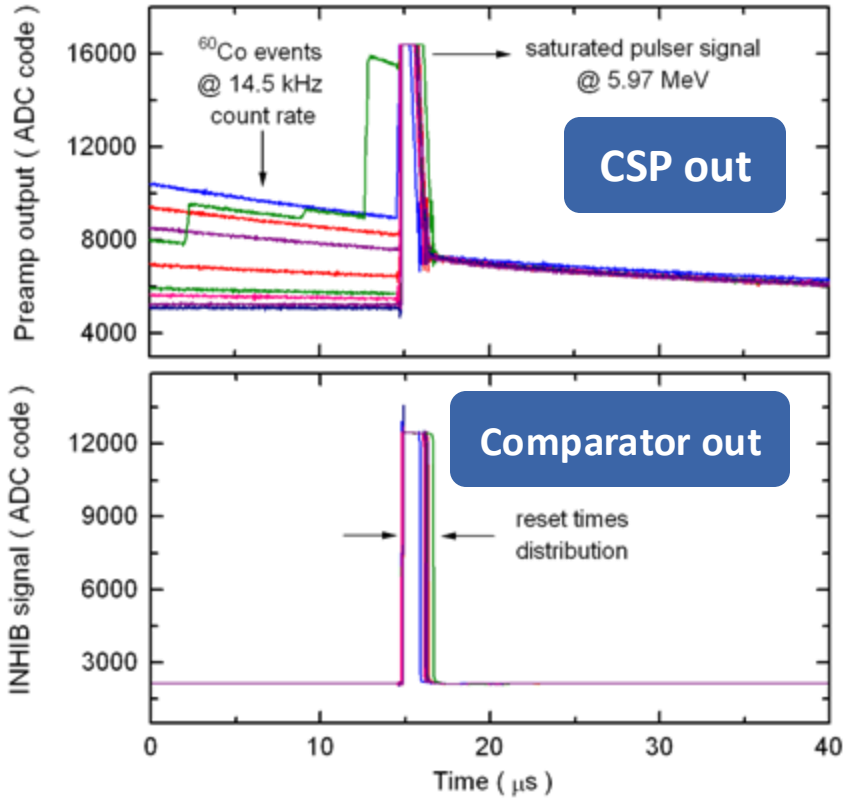


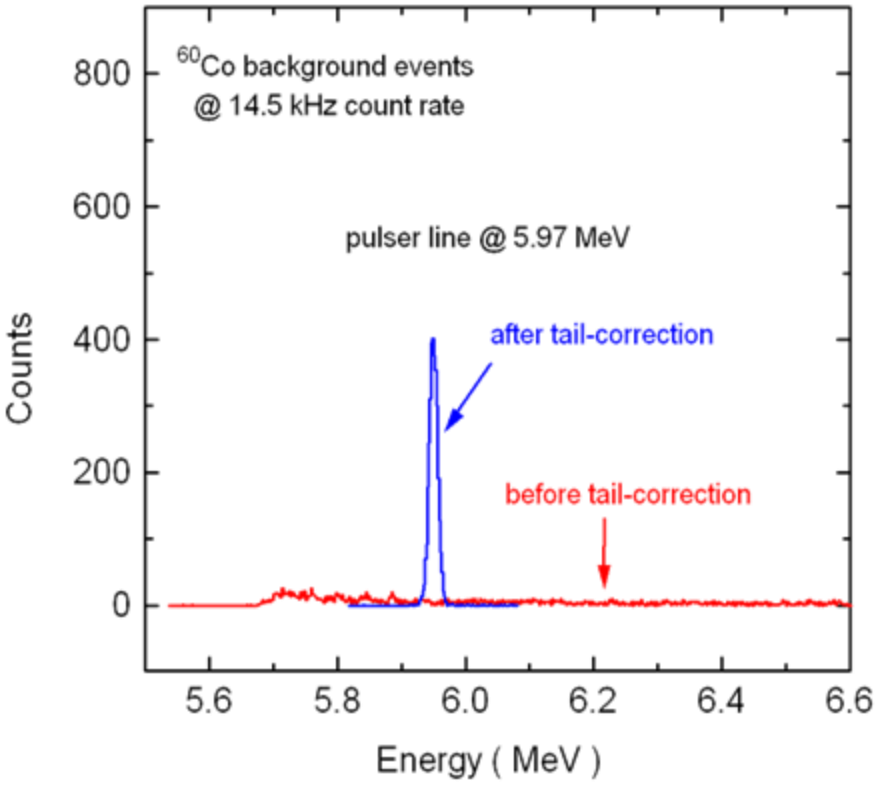


Dependency of the energy measurement from the baseline value

Pile-up effects at high counting rate

14.5 KHz

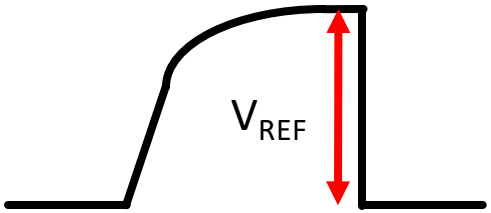




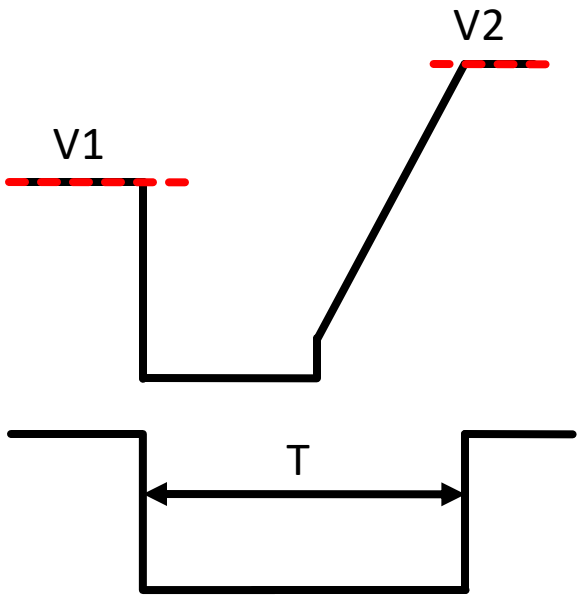
An algorithm to correct the spectra from the baseline dependency

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

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

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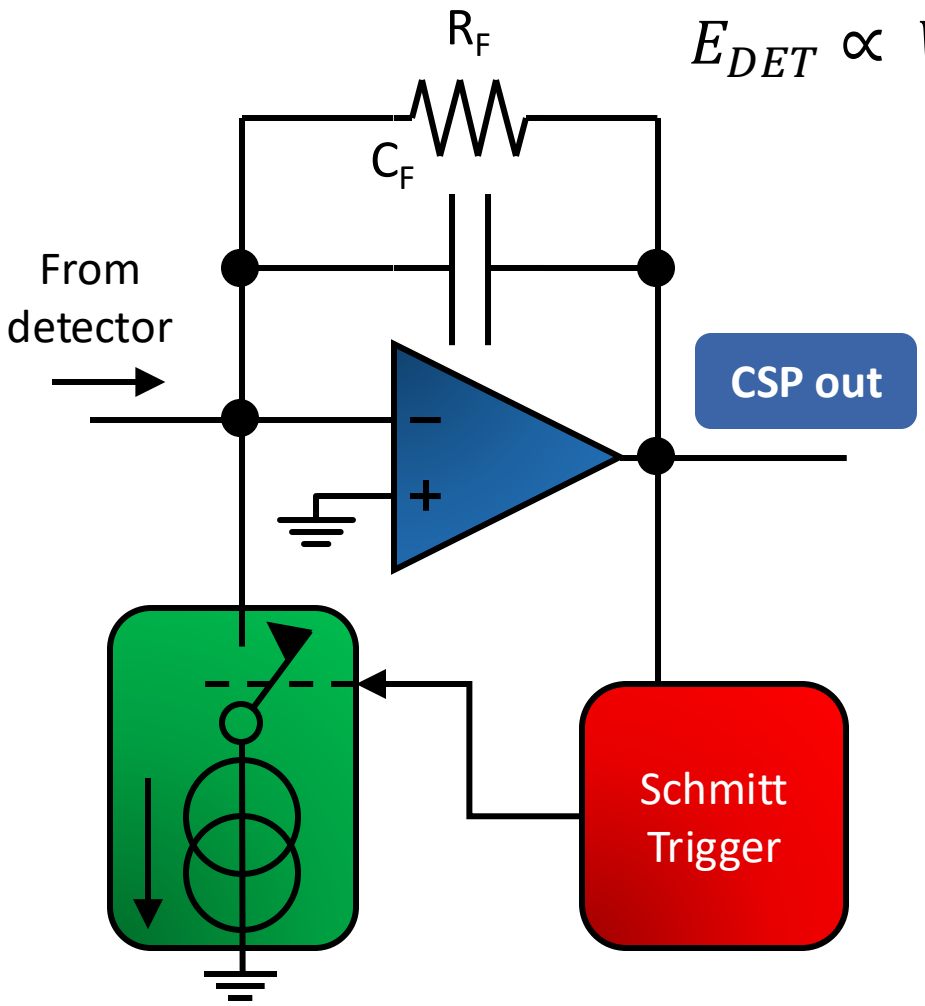

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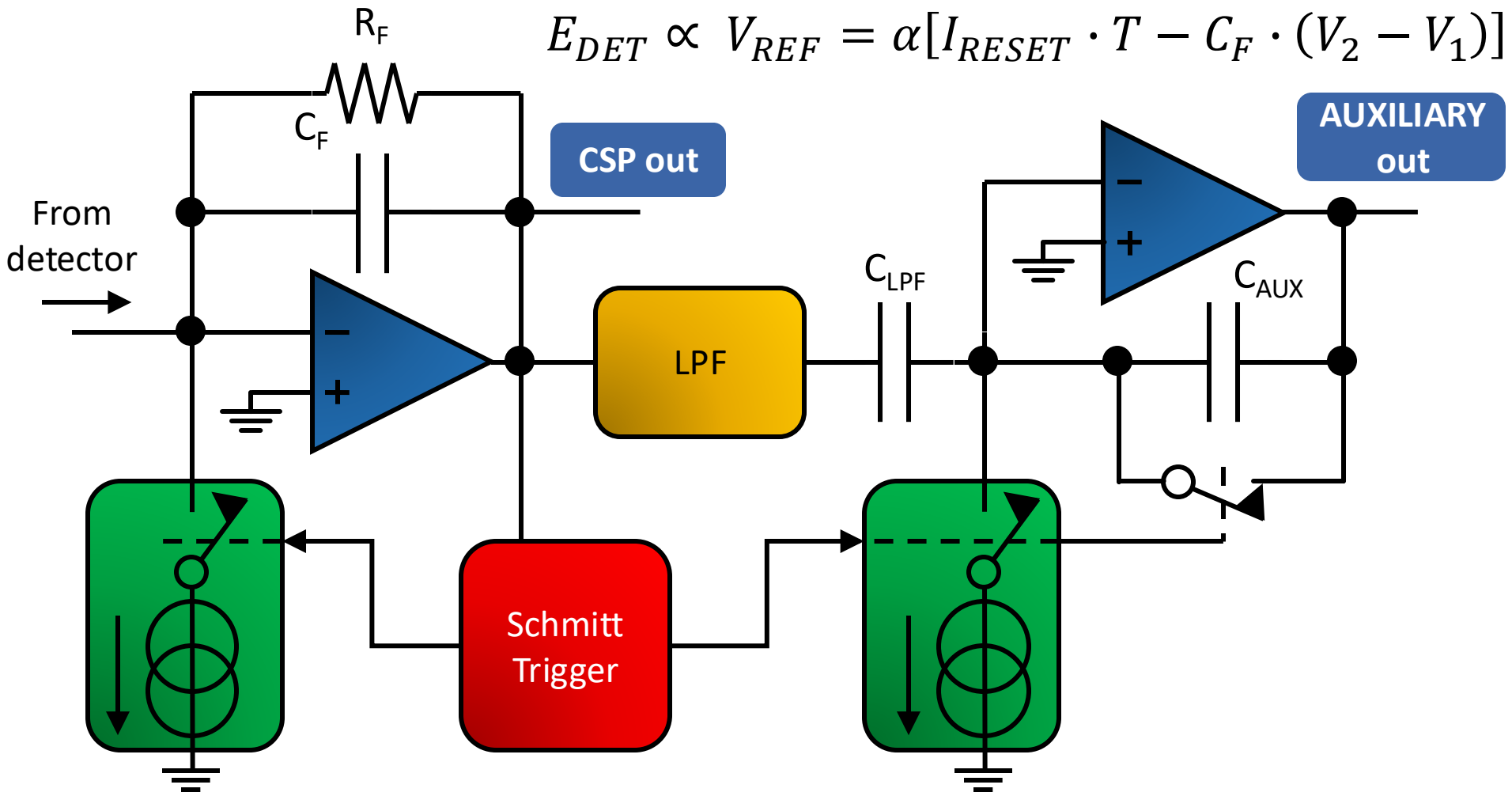
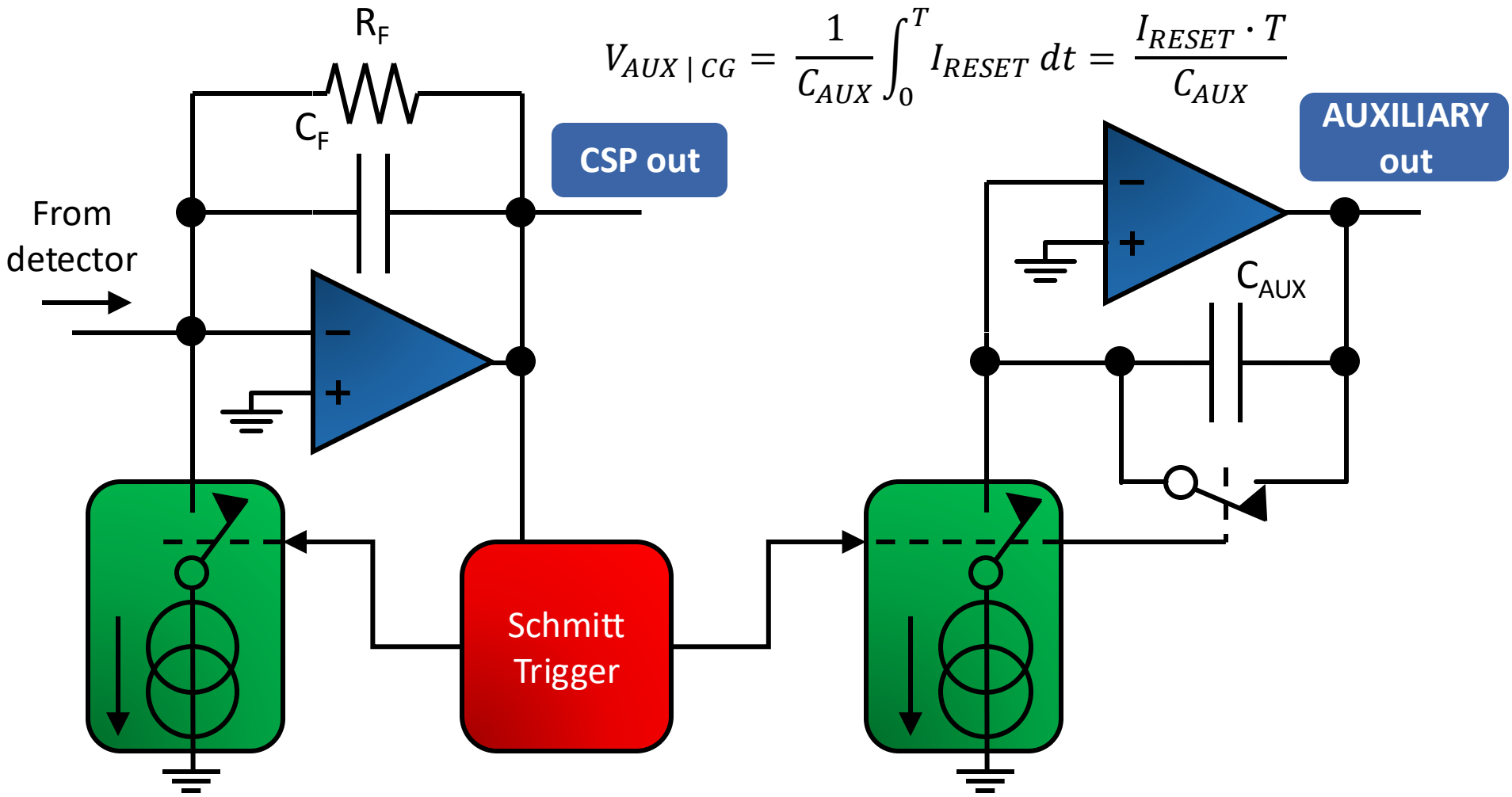


An algorithm to correct the spectra from the baseline dependency

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



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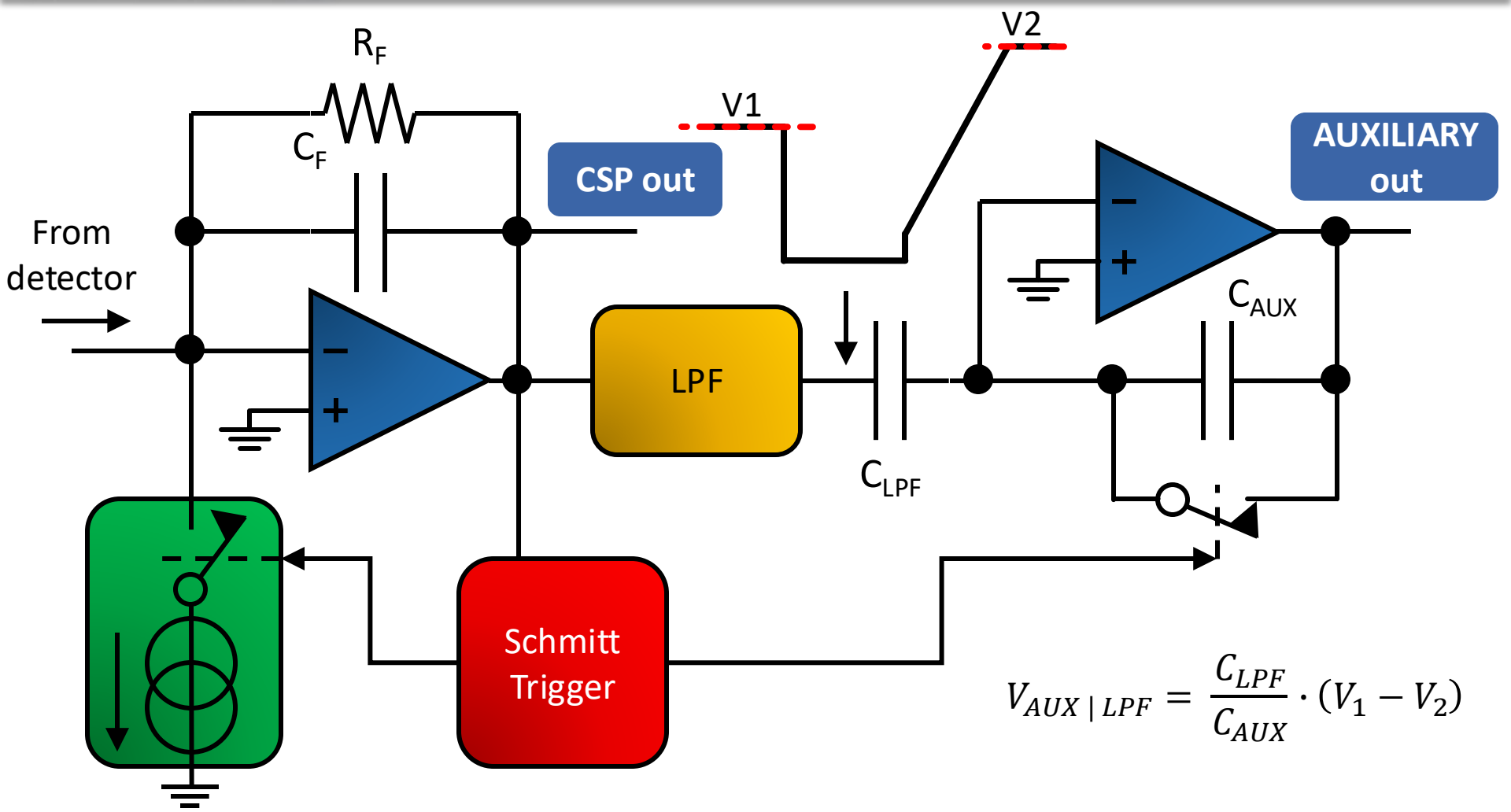
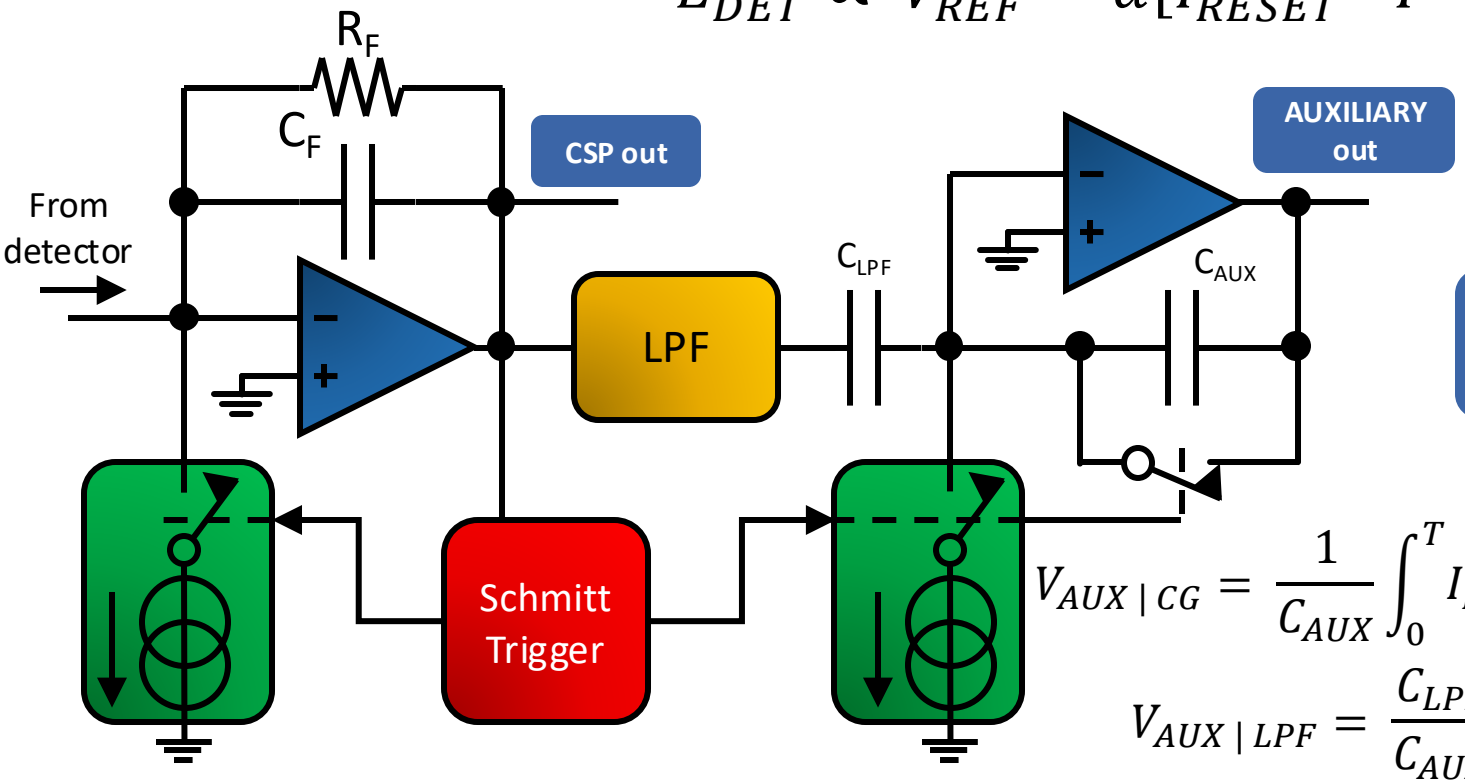


$$V_{AUX\,|\,LPF} = \frac{C_{LPF}}{C_{AUX}} \cdot (V_1 - V_2)$$

An algorithm to correct the spectra from the baseline dependency

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



$C_F = C_{LFP}$

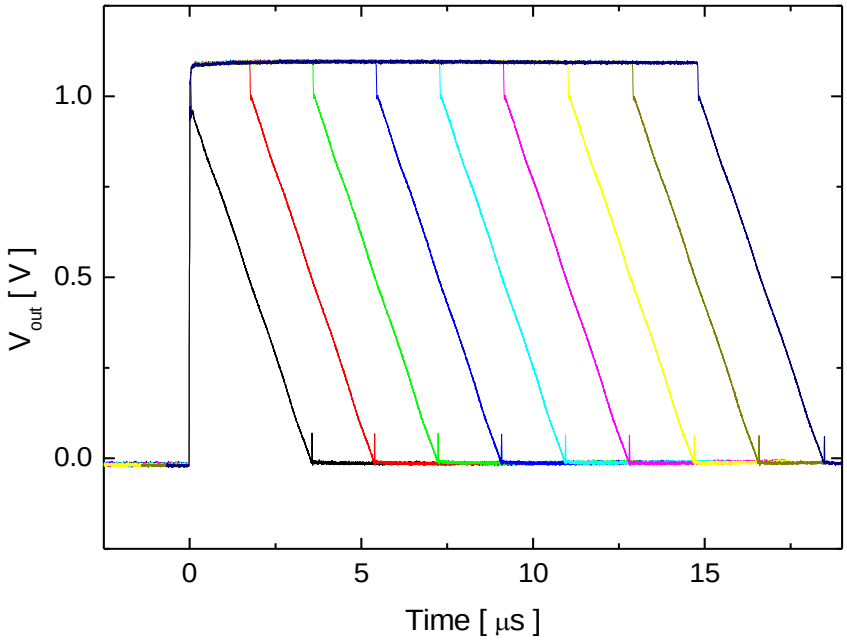
$$V_{AUX\,|\,CG} = \frac{1}{C_{AUX}} \int_0^T I_{RESET}\, dt = \frac{I_{RESET} \cdot T}{C_{AUX}}$$

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

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

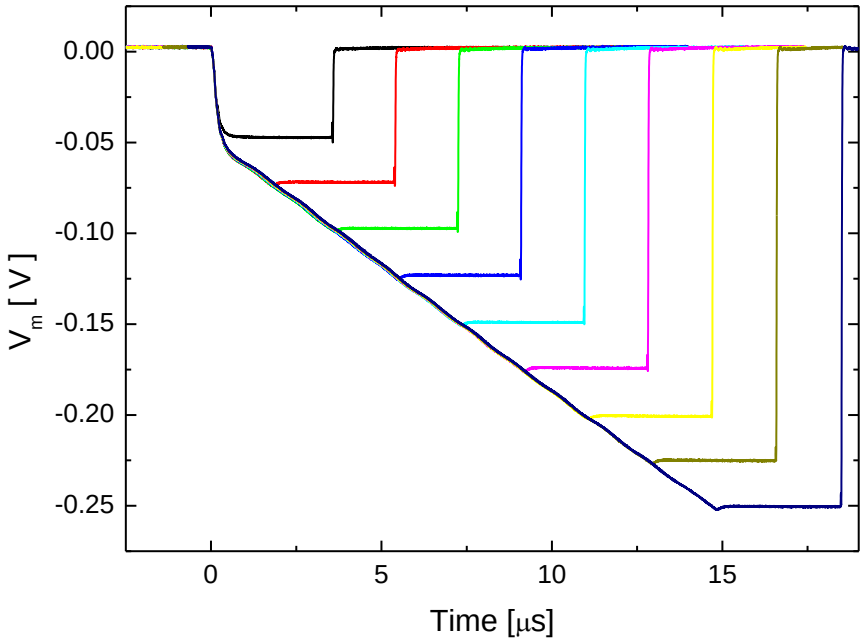
Experimental results: linearity test

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

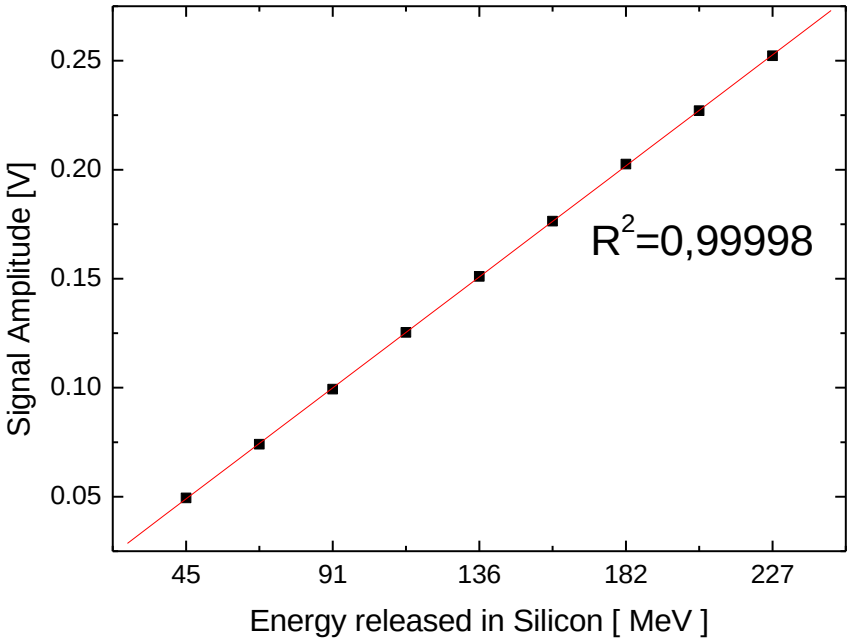
AUXILIARY out



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

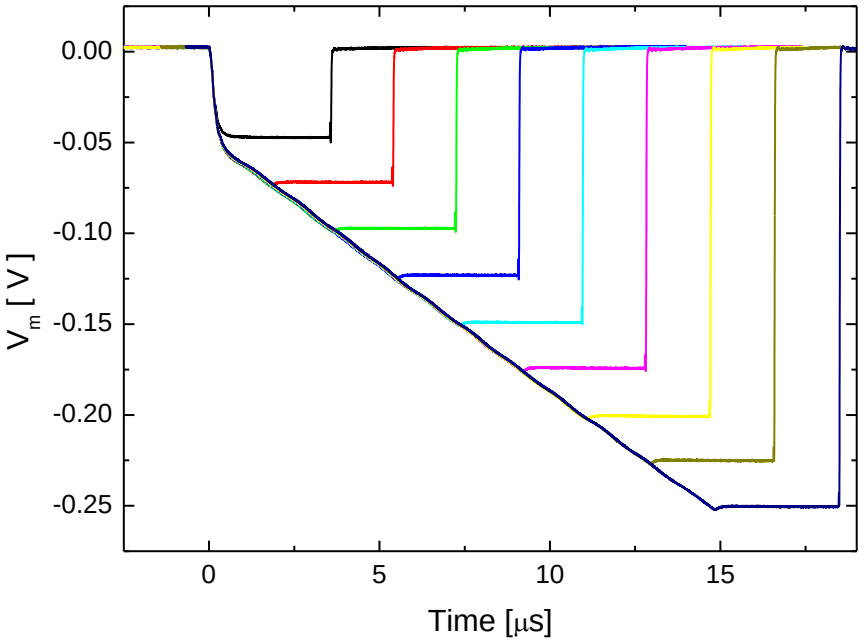
Experimental results: linearity test

Linear fit



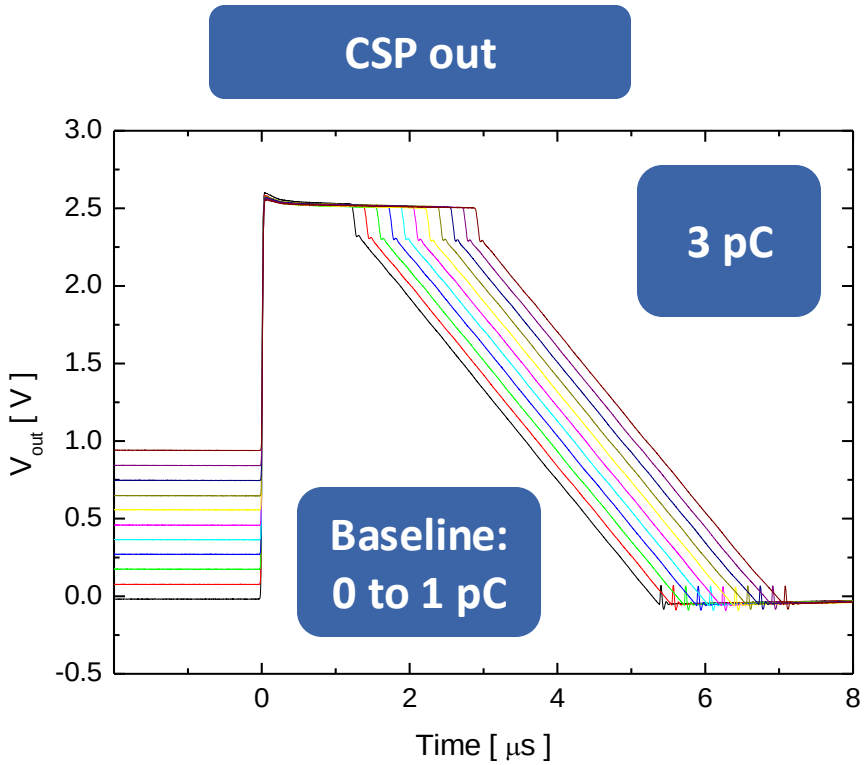
- 2 pC to 10 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor

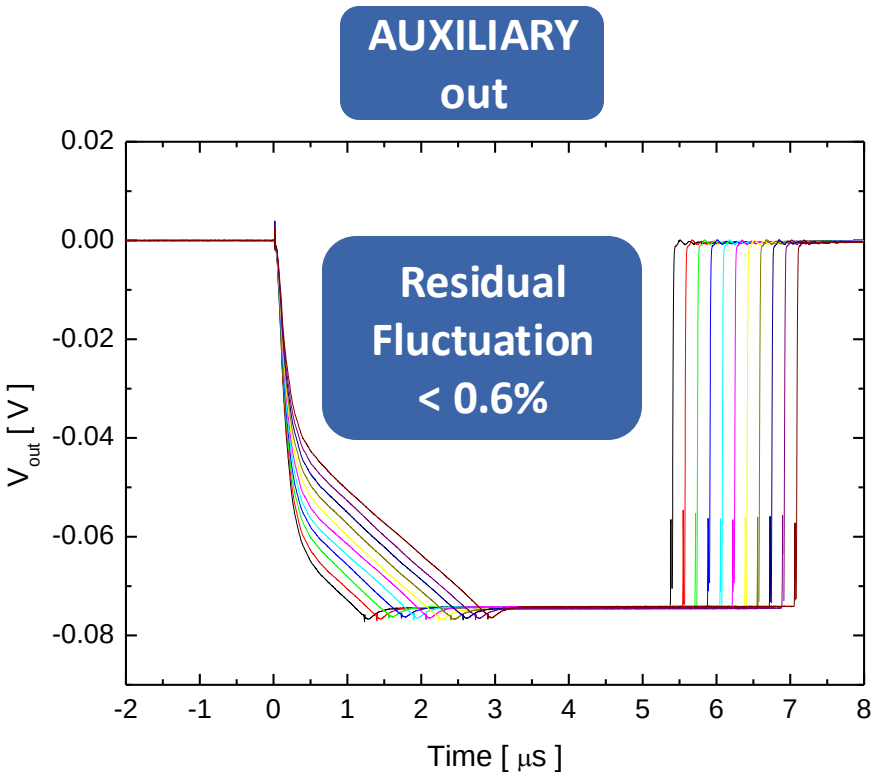
AUXILIARY out



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

Experimental results: linearity test

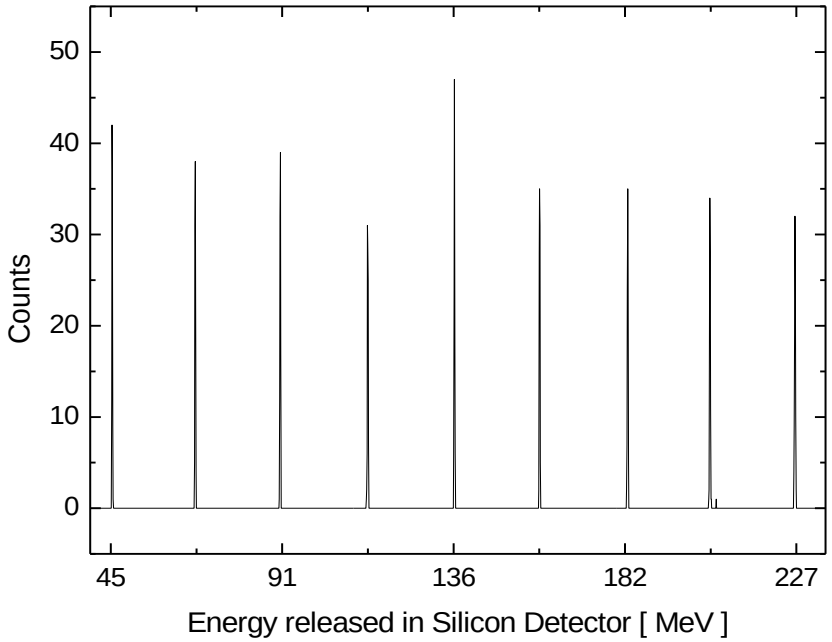




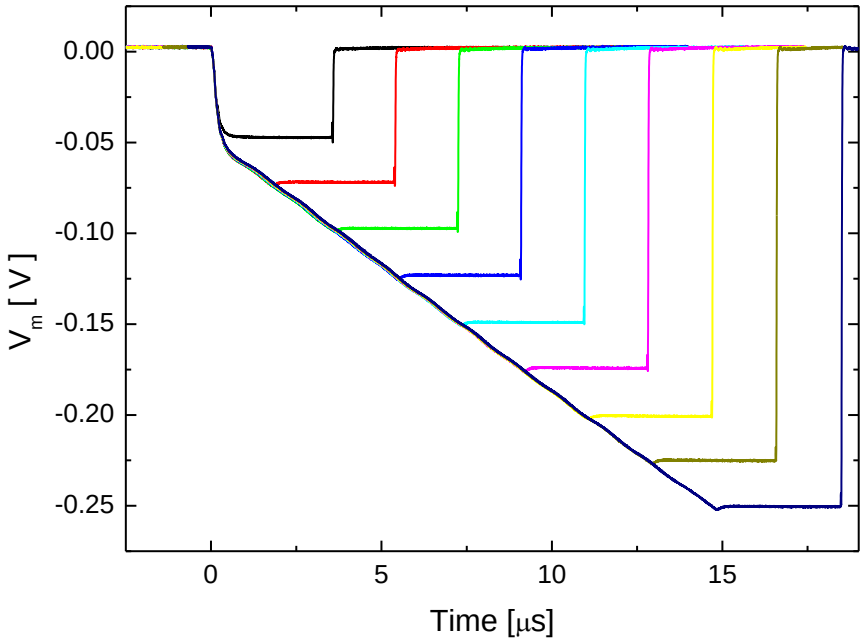
- 3 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor. From 0 to 1pC of residual charge on the input node
- The auxiliary TAC structure produces signals that change in shape but keep the same amplitude!

Experimental results: linearity test

Amplitude histogram



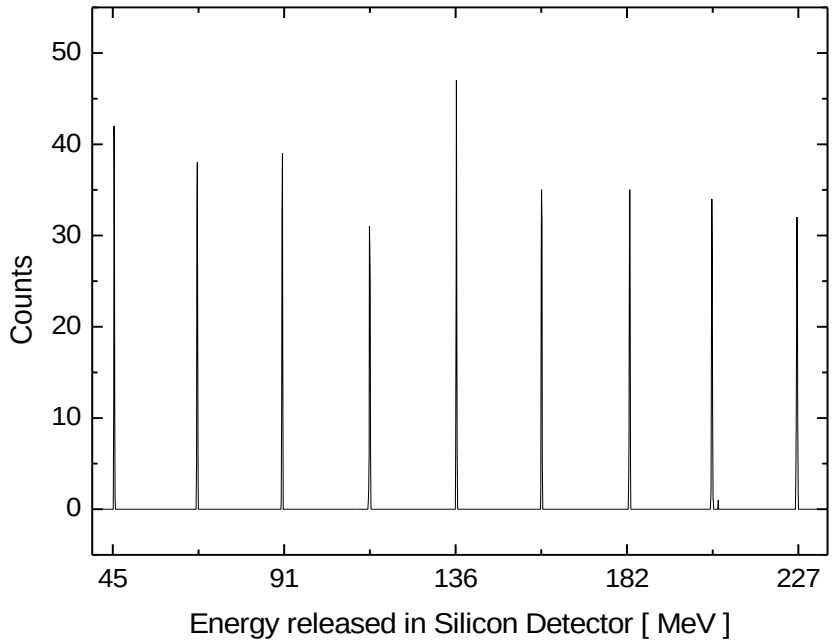
AUXILIARY out



- 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: linearity test

Amplitude histogram



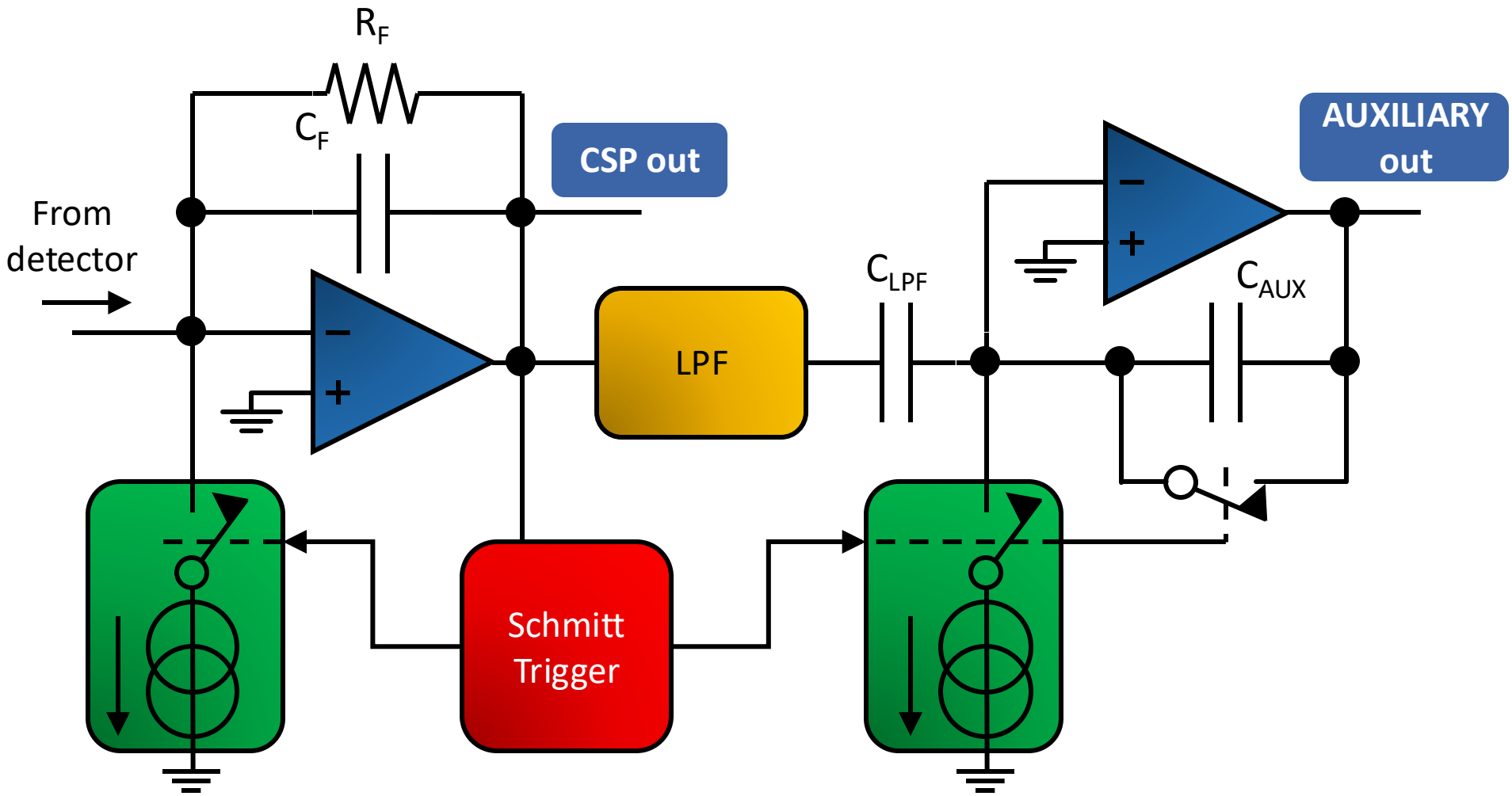
- 2 pC to 10 pC charge signals injected on the input node of the CSP with a pulser through a 1 pF test capacitor. 100 signals acquired for each peak

Peak resolutions

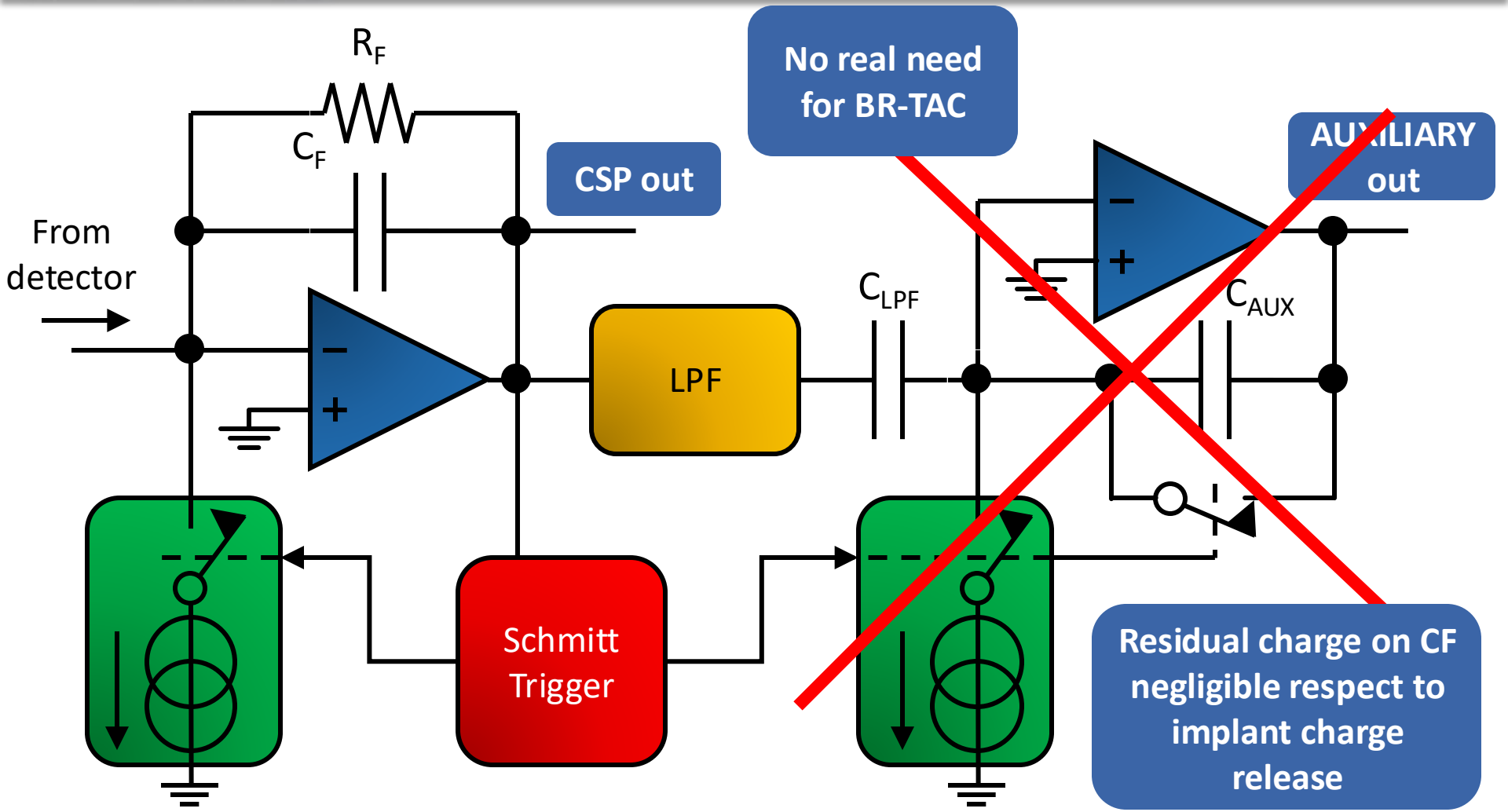
Input Charge [pC]	Signal amplitude [mV]	Peak width FWHM [mV]	Peak width FWHM [%]
2	49.394	2.10E-01	0.43
3	74.073	2.43E-01	0.33
4	99.329	2.29E-01	0.23
5	125.33	2.96E-01	0.24
6	151.08	2.47E-01	0.16
7	176.39	2.27E-01	0.13
8	202.56	2.69E-01	0.13
9	227.03	5.35E-01	0.24
10	252.27	3.47E-01	0.14

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

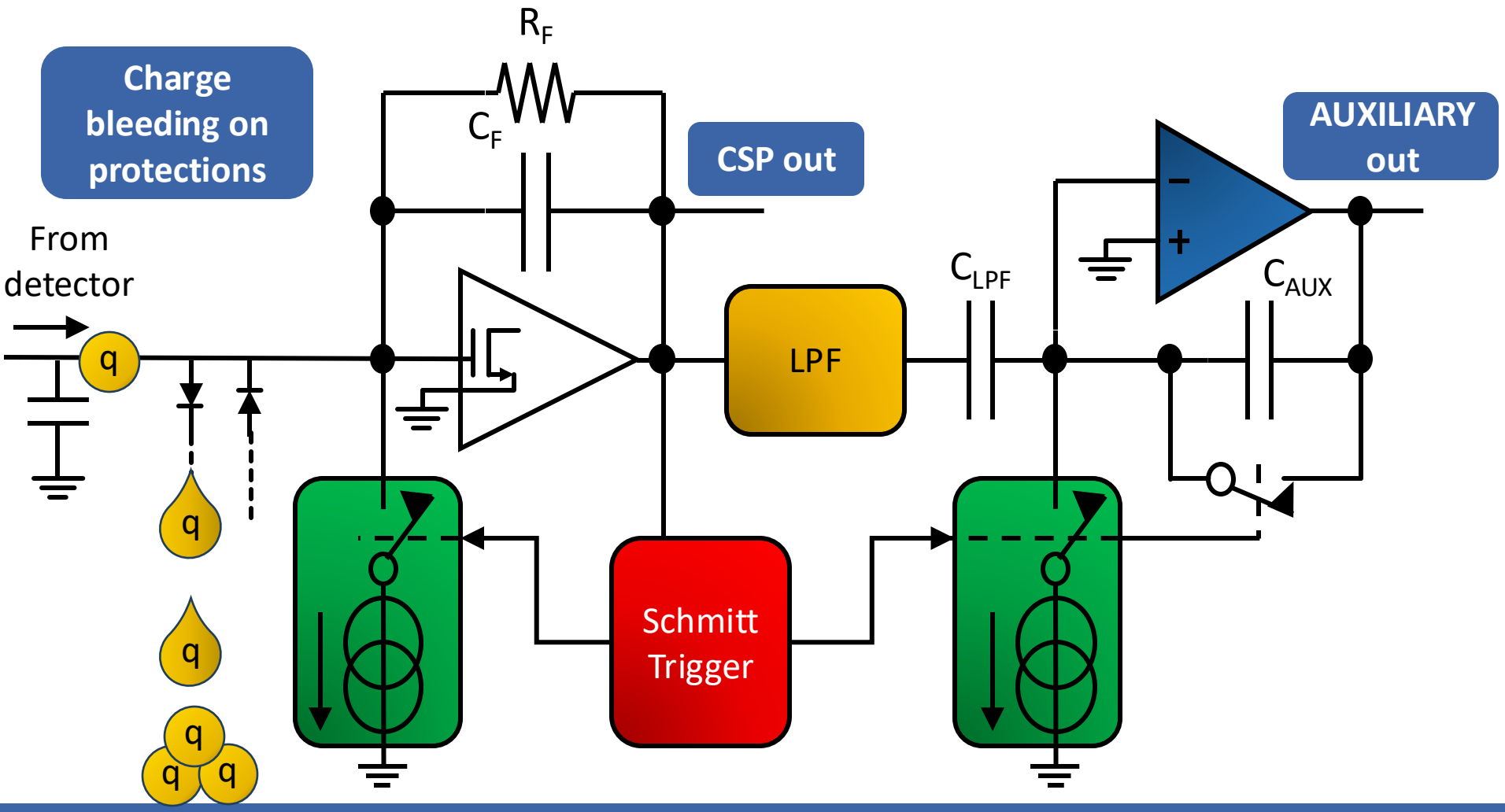
An outlook on decay spectroscopy application



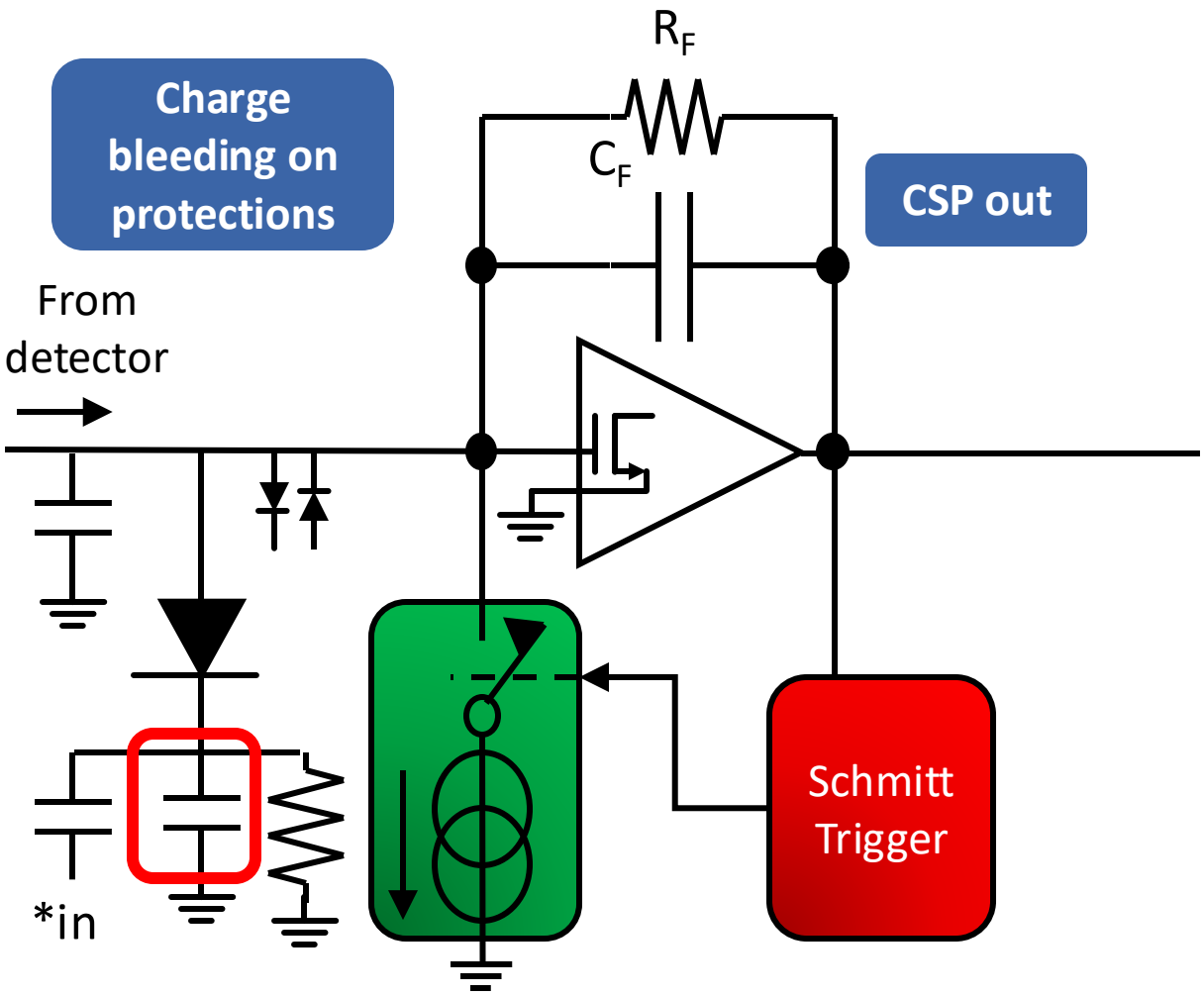
An outlook on decay spectroscopy application

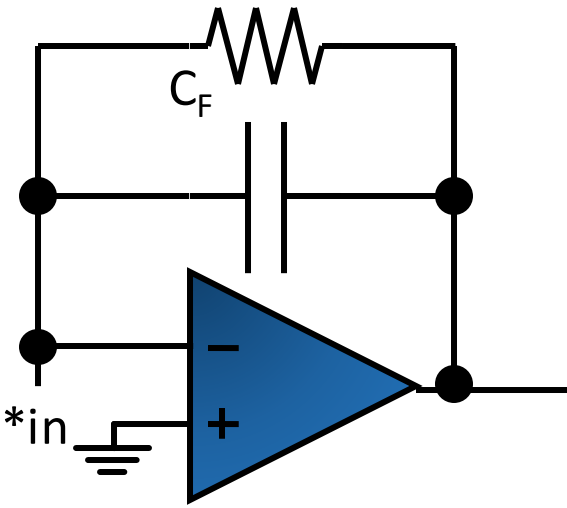


Intrinsic issues (and how to solve them)



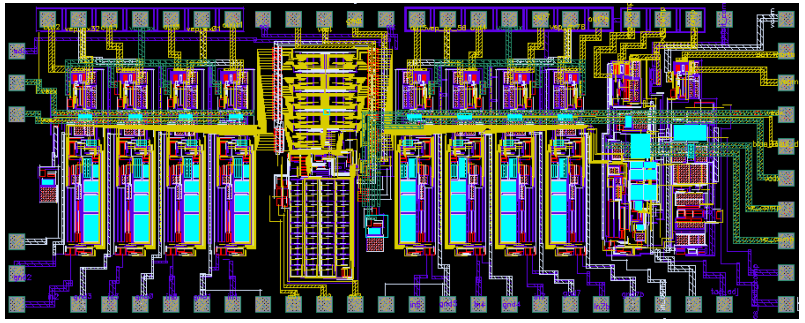
Intrinsic issues (and how to solve them)



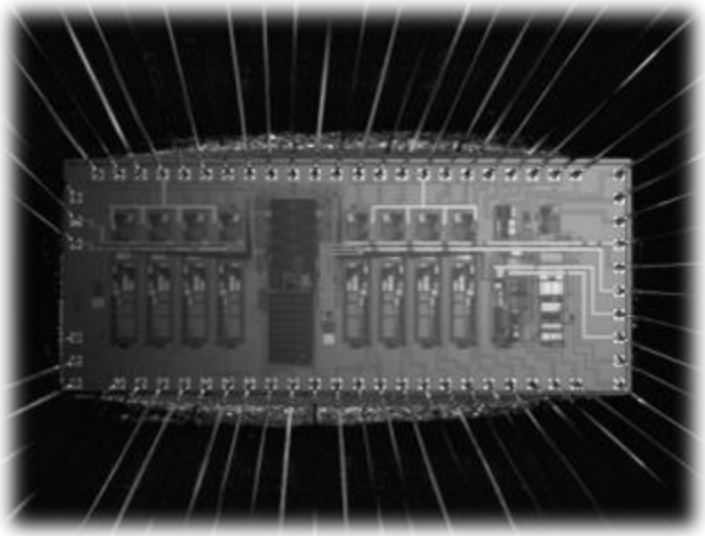


Conclusions

- 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 algorithm was implemented in an analog circuits that performs the operation on-line and is not influenced by the signal's baseline

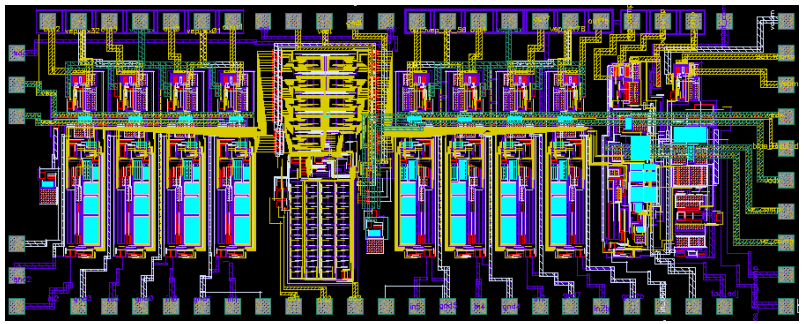


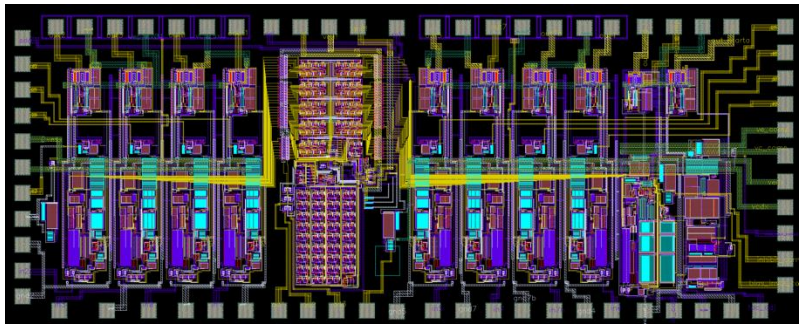
Perspectives

New ASIC preamplifier for signals with opposite polarity: Ready, tested.

CSP implementation for decay spectroscopy applications

Experimental results: hopefully before end of 2025





Active Stoppers for Decay Experiments

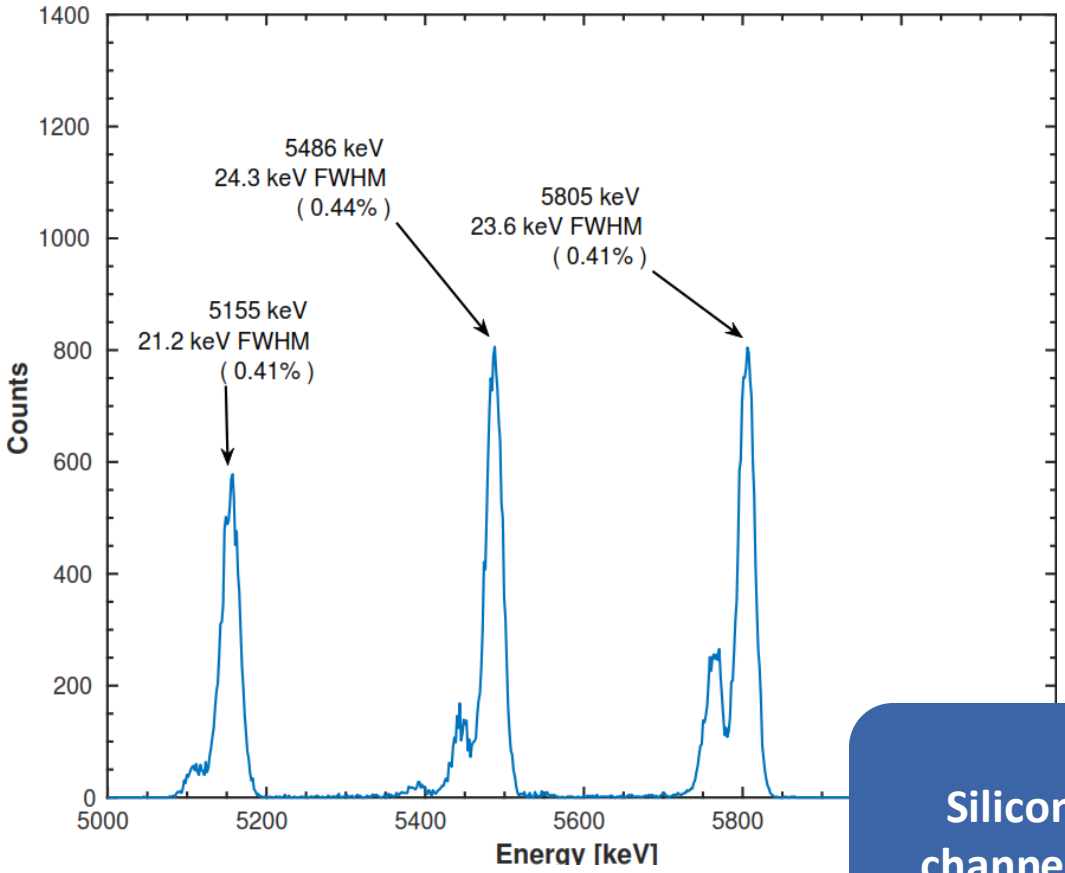
Valencia, Spain, March 24-26 2025

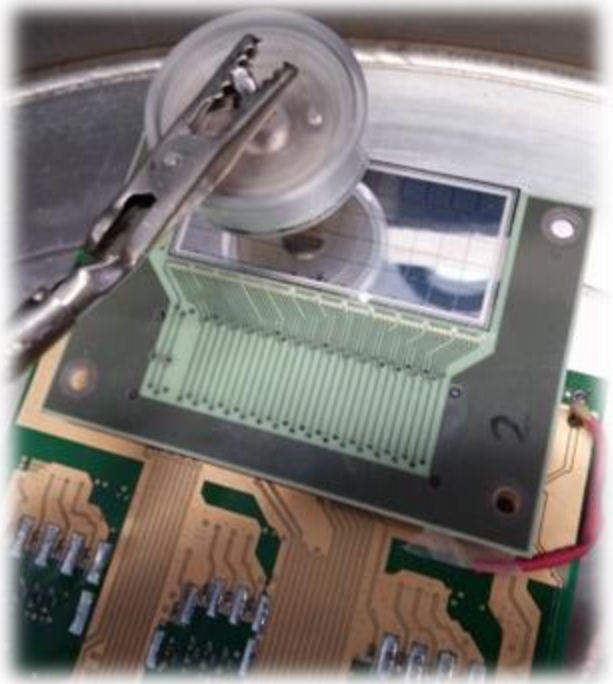
Organizing Committee:

Anabel Morales (IFIC, CSIC-UV)
Tom Davinson (U. Edinburgh)
Andrés Gadea (IFIC, CSIC-UV)
Nic Hubbard (GSI)
Shunji Nishimura (RIKEN)
Marta Polettini (GSI)
Jelena Vesic (IJS)

Thank you

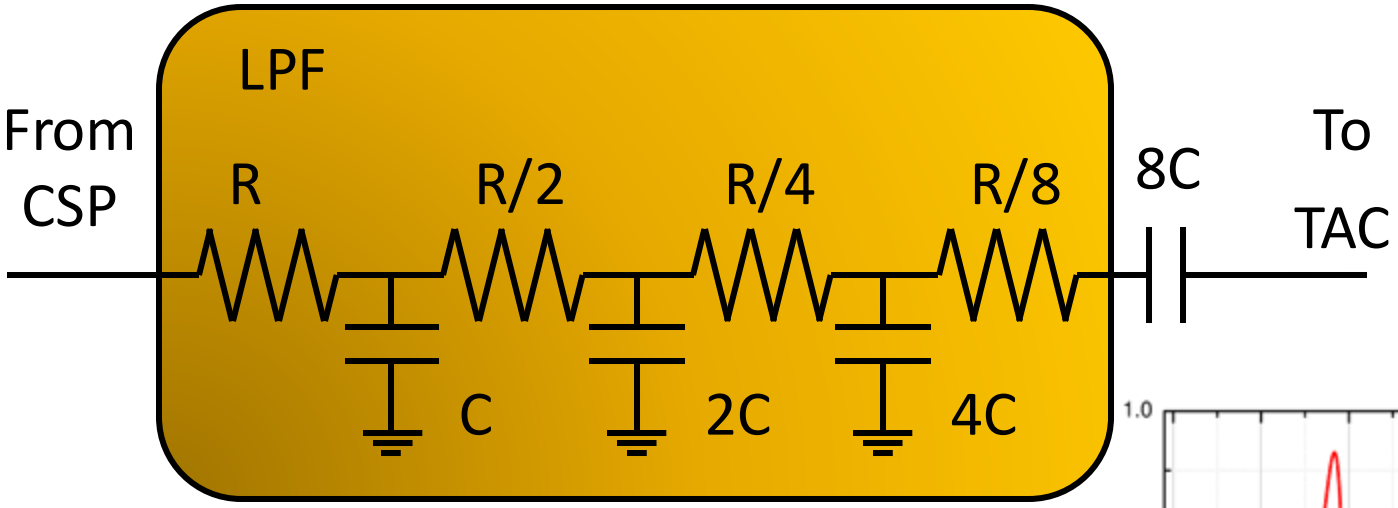
Experimental tests with detector (previous chip version)

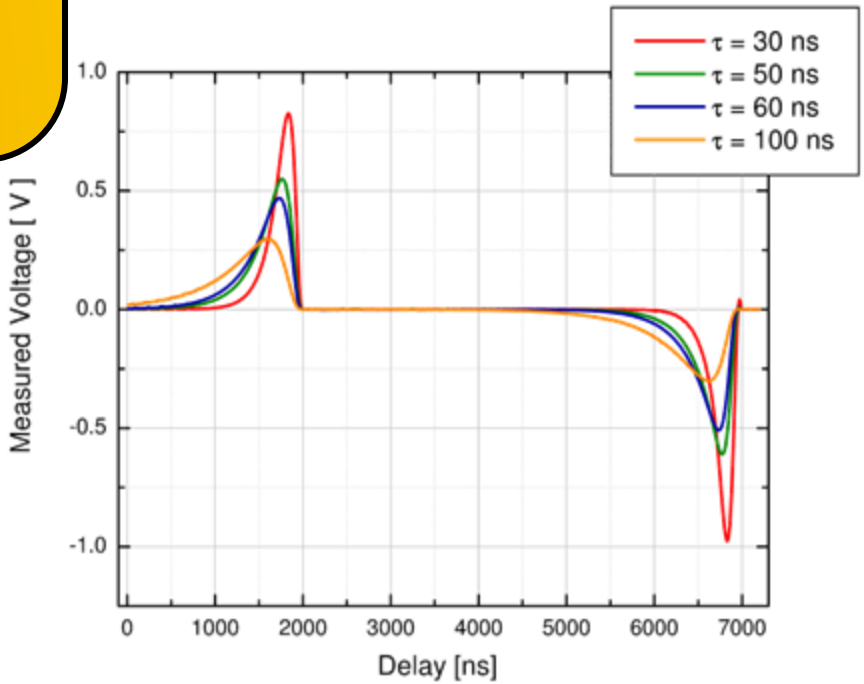




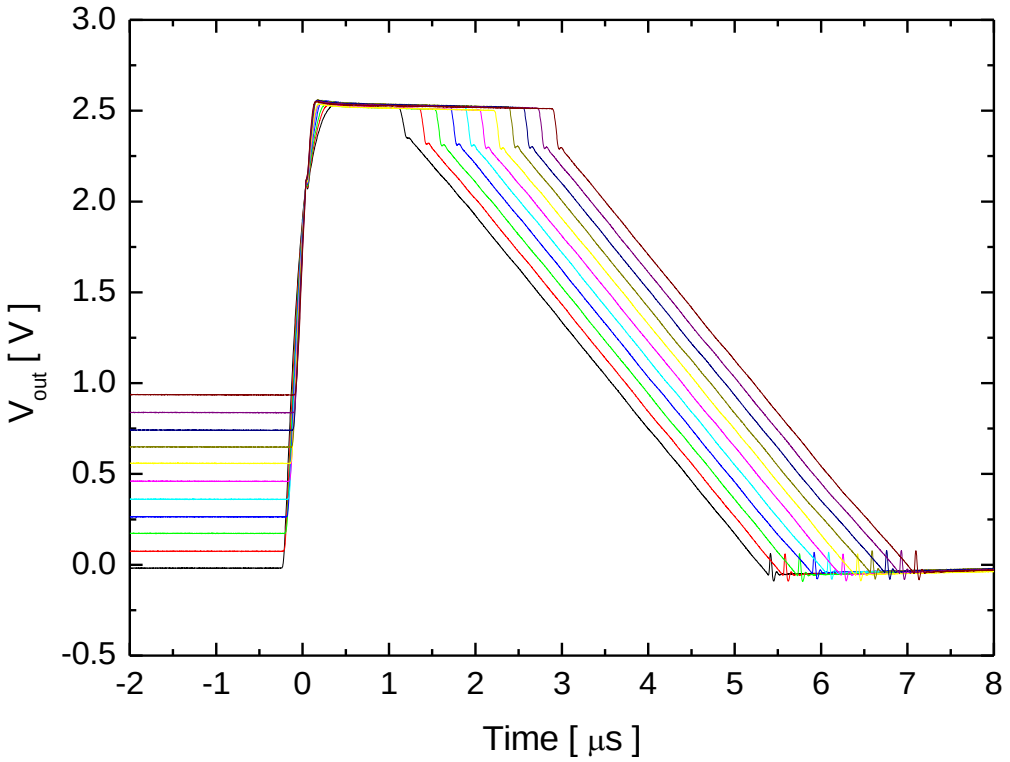
Silicon detector 1 mm thick, 32 active channels, Am-Cu-Pu mixed alpha source

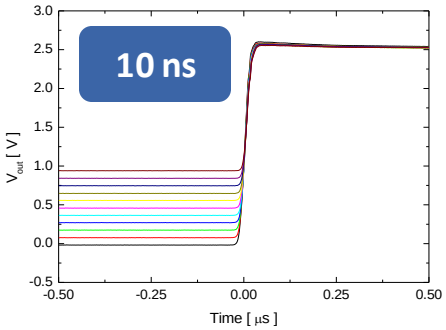
Low-pass filter

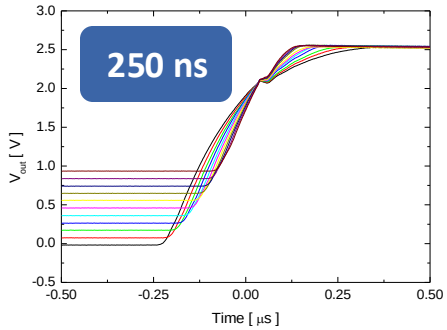


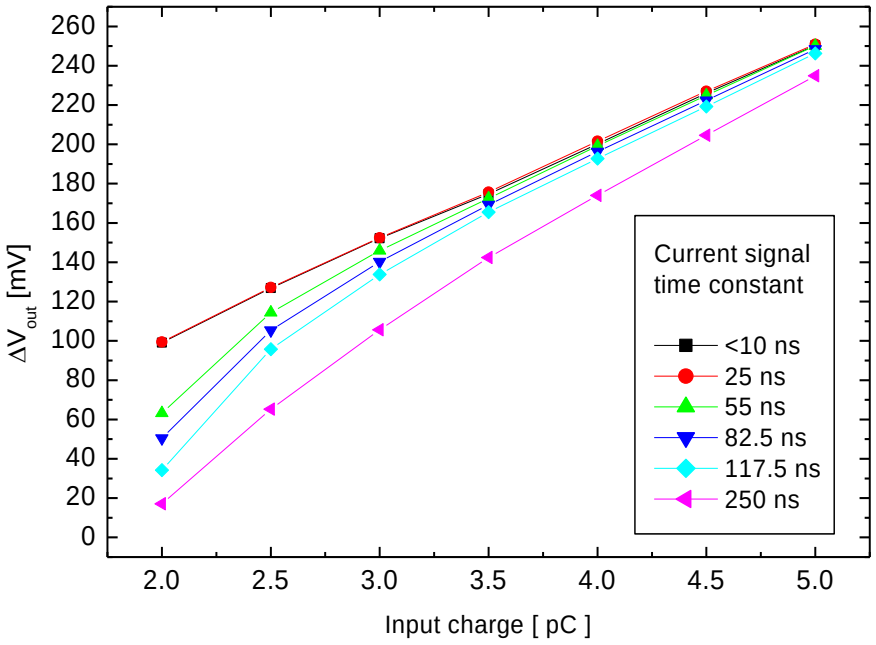


Limits of the algorithm









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