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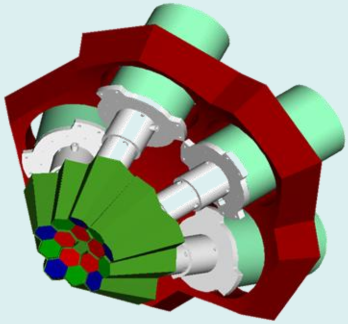

Cutting-edge circuit technology able to boost the dynamic range of charge-sensitive preamplifiers far beyond their saturation limit

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Outline

- Context and goal of the research
- Large volume HPGe detectors & required specs for charge preamps
- The issue of saturation & dynamic range for integrated preamplifiers
- Technique to handle saturated signals with low-noise preamps
- Reset-mode high-resolution spectroscopy
- Charge information recovery: extending the dynamic range beyond the saturation limit of the preamplifier
- Conclusions

Context and goal

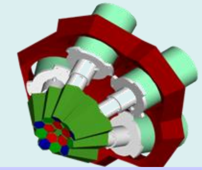
Context

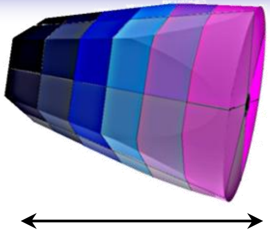
- Milano INFN funded experiment "Synergy"
- Activities of European Network "SGFD" (Synergy Group for Front-End Electronics and Data Acquisition) of NUSTAR collaboration

Goal of the research

- New paradigm: high-resolution spectroscopy is possible even working with a deeply saturated CSP !

Large volume HPGe detectors





~ 9 cm

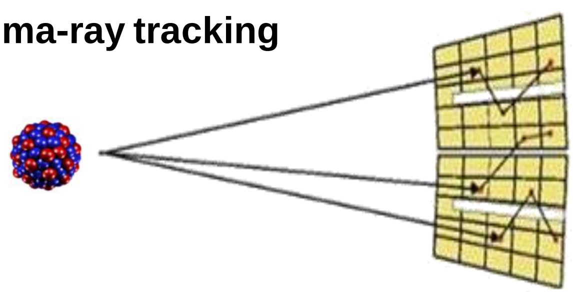
High-resolution gamma-ray spectroscopy ➔ investigation of nuclear structure under very extreme conditions of stability

Main features:

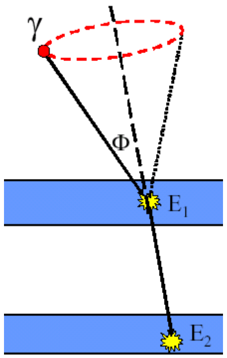
- operated at **cryogenic temperature** (liquid nitrogen used as cooling medium @ 77 K)
- electrodes capacitance values: 20-100 pF
- energy of detected gamma-rays: from **a few keV to a few tens of MeV**
- **excellent intrinsic energy resolution: 0.1% - 0.2%** in the typical 1 MeV region
- segmentation of the outer electrode ➔ position-sensitivity: **~ 1 mm 3D resolution**

Gamma-ray tracking

emitting radionuclide



Gamma-ray Compton imaging can take advantage of the excellent energy/position resolution of HPGe



Charge-preamplifier specifications

- low noise (gamma spectroscopy grade: 0.1-0.2 % @ 1MeV)
- excellent stability of the gain and of the shape of the preamplifier response (loop gain ~ 10^3)
- wide bandwidth: rise time of ~ 20 ns (pulse shape analysis)
- low power consumption (especially for the devices operated in the cryostat)
- **LARGE DYNAMIC RANGE**:

  - at least ~10^4 : from a few keV to 10-20 MeV

  - up to ~30 MeV depending on the physics experiment (i.e. giant resonances)

  - minimization of the dead time in a much larger energy range up to 100-200 MeV

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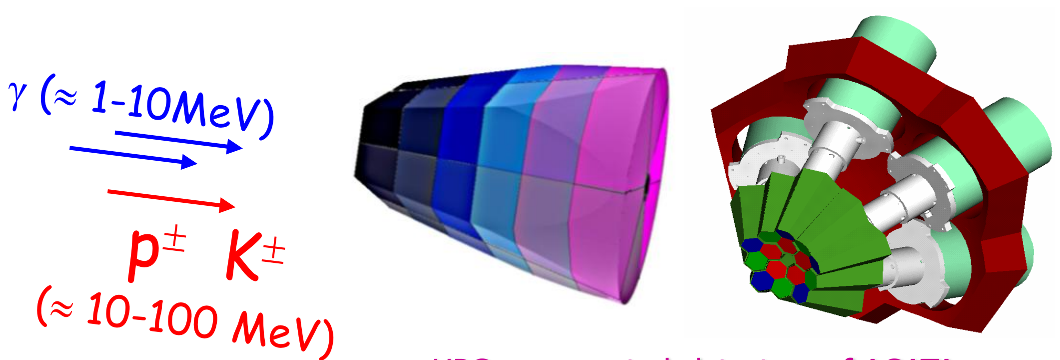
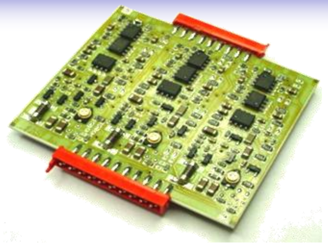
extremely hostile background of highly energetic charge particles in next-generation nuclear physics experiments with high-intensity exotic beams



HPGe segmented detectors of AGATA (Advanced GAmma-ray Tracking Array)

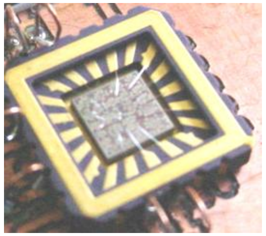
The issue of a wide dynamic range

Old-style solution: hybrid DISCRETE preamplifiers



- high flexibility in the design
- use of high voltage power supply (ex: +/- 12 V)

Modern CMOS integrated solutions: a mandatory task



the high segmentation of the read-out electrodes yields a higher and higher count of read-out channels

- small dimensions & low power dissipation
- radio-purity and full functionality at cryogenic temperature

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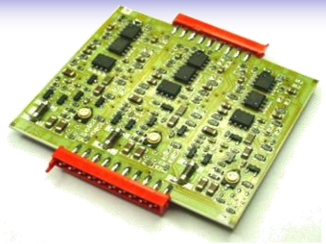

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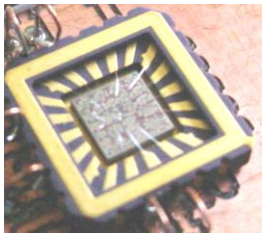

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Intrinsically low available voltage swing of scaled CMOS technologies

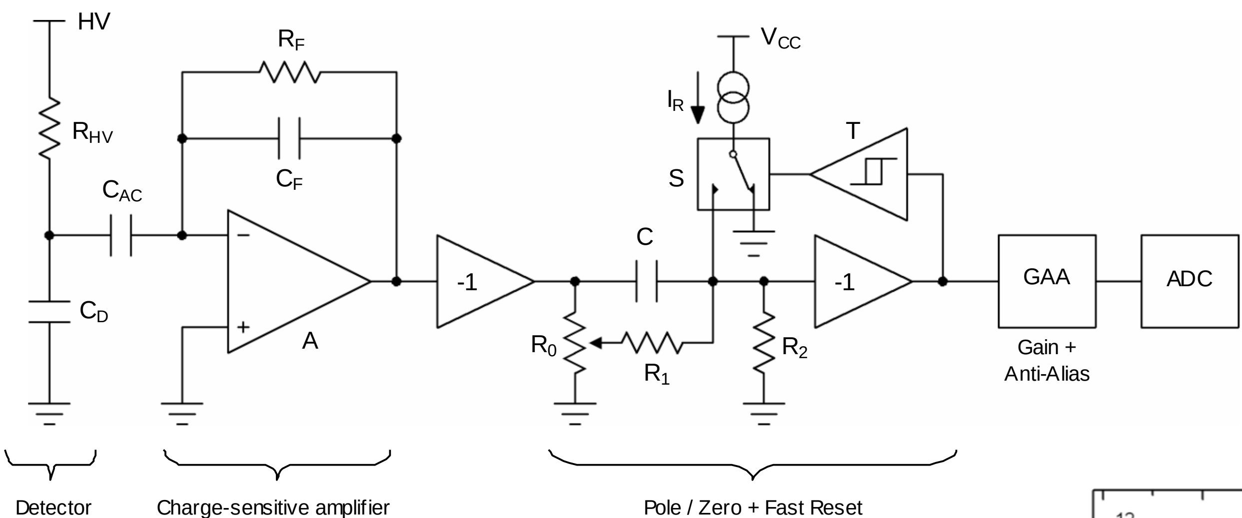
⬇

A decrease of the preamplifier sensitivity (energy-to-voltage gain) would compromise the signal-to-noise ratio and the spectroscopic performances

Saturation of a CMOS preamplifier for HPGe detectors is expected for input energies > 5-10 MeV

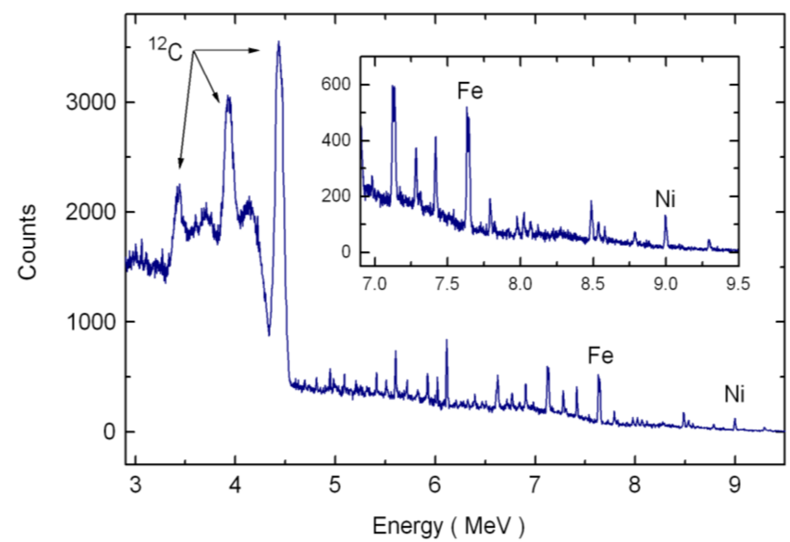
"Reset-mode" spectroscopy

"Reset-mode" high-resolution spectroscopy has been demonstrated



Hybrid charge preamplifier with second-stage active fast reset

Reset-mode ^{241}Am+Be spectrum
resolution on Ni line: 0.21% @ 9MeV

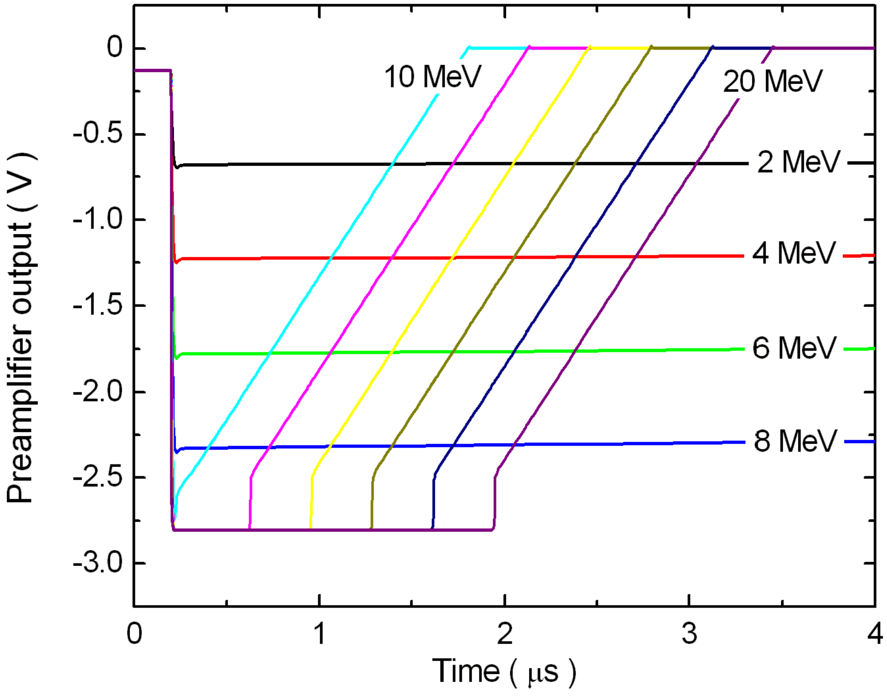


See: F.Zocca, A.Pullia, D.Bazzacco, G.Pascovici, "A Time-over-Threshold technique for wide dynamic range gamma-ray spectroscopy with the AGATA detector", IEEE Trans. Nucl. Sci., vol. 56, no. 4, pp. 2384-2391, Aug. 2009

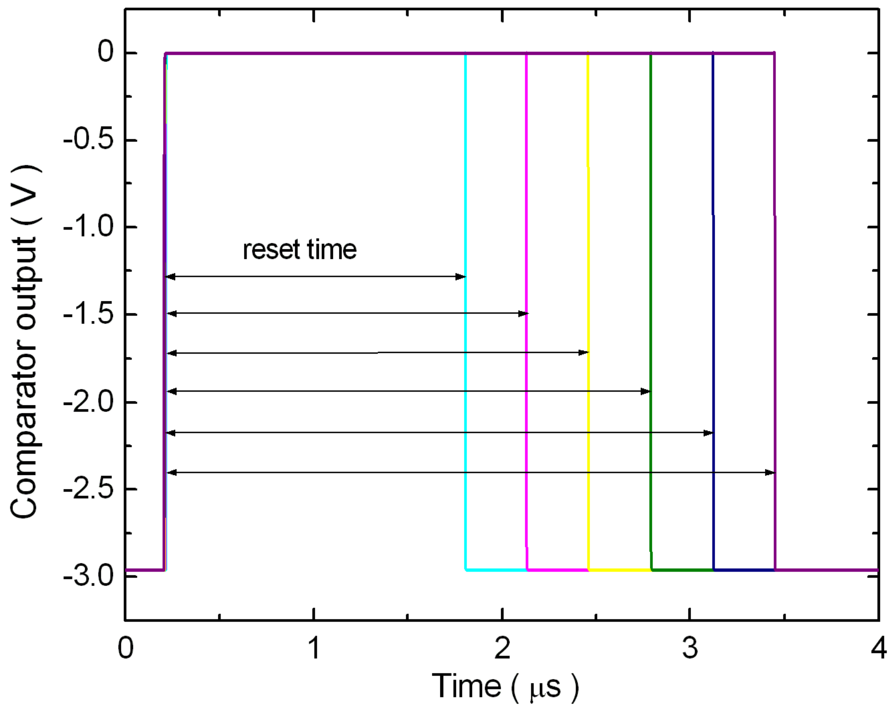
Active Fast Reset

Computer simulations

Preamplifier output signals of different amplitudes (negative holes signals)

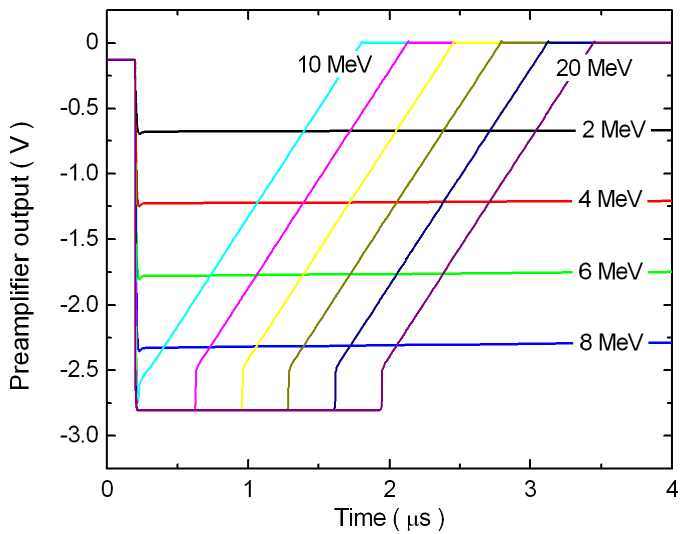


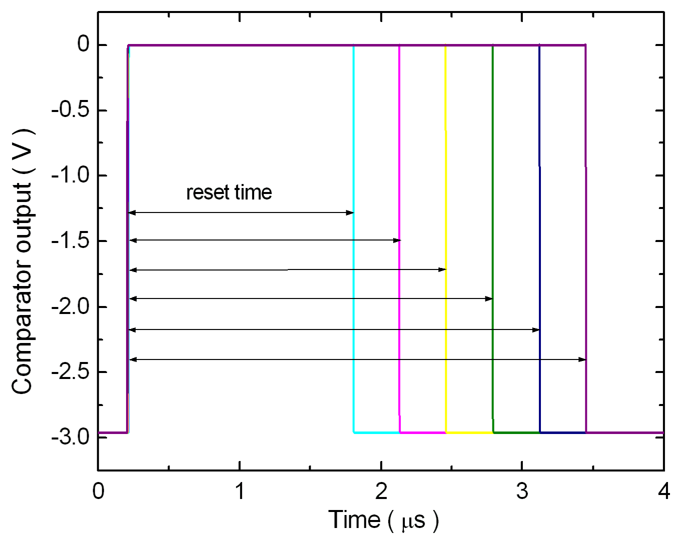
Digital pulses delivered by the comparator: a time-over-threshold measurement provides the reset time

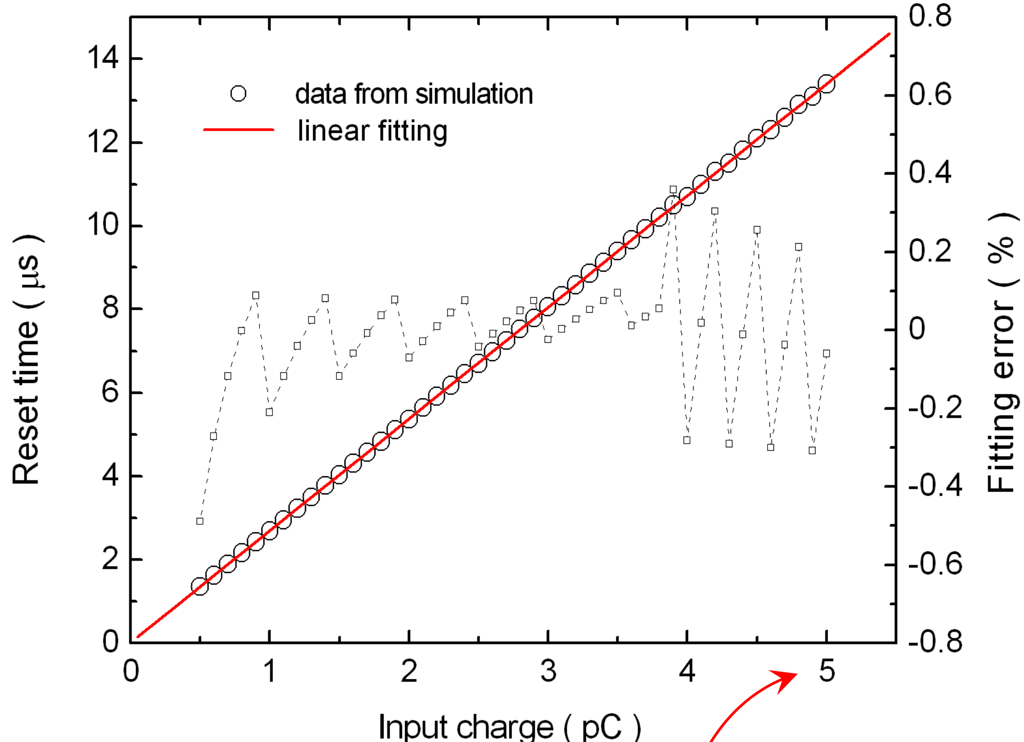


Proportional relation between input charge and reset time

Reset time - Input charge Relation







The percent error in the fitting mainly comes from the numerical approximation of the simulation program and has to be considered as a maximum upper limit

Charge	*Energy in Ge*
1 pC	18.2 MeV
2 pC	36.4 MeV
3 pC	54.5 MeV
4 pC	72.7 MeV
5 pC	90.9 MeV

Conclusions

- Design & computer simulation of a JFET-CMOS preamplifier (0.35μm) for HPGe detectors equipped with a fast reset device for charge sensing stage de-saturation
- Dead time minimization in the cases of high background counting rates
- Charge measurements even in a condition of deep saturation ➔ boost of useful dynamic range for high-resolution energy measurements
- Experimental tests to be performed on the realized test chip