University of Milano
INFN - Milano

Department of Physics

JRA 02 - AGATA

Going beyond the ADC limit in AGATA with a Time-over-Threshold technique and first results with an ASIC preamplifier for Ge detectors

Francesca Zocca

FREEDAC meeting Ljubljana 2008, May 28th

Time-over-Threshold (TOT) technique for AGATA preamplifiers

The issue of ADC saturation & system dead time

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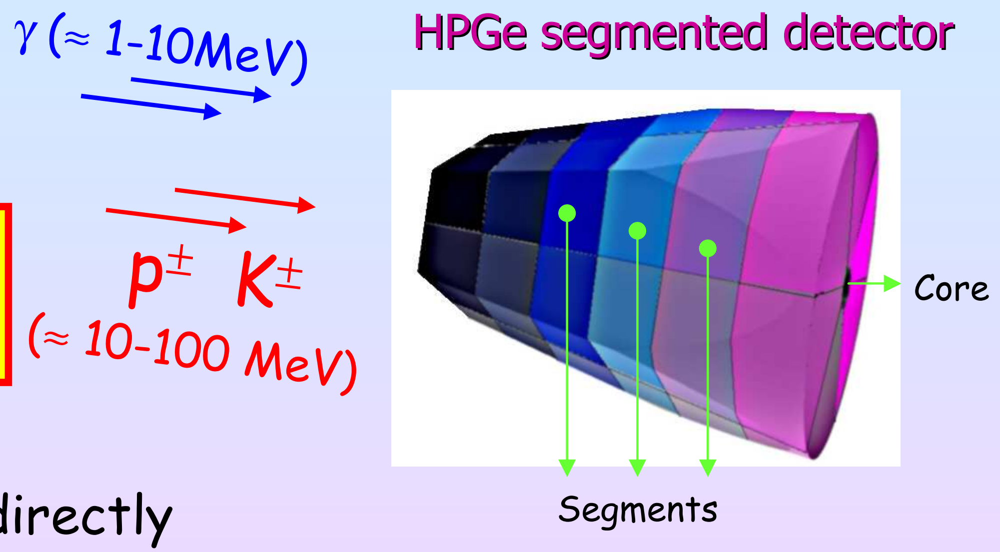
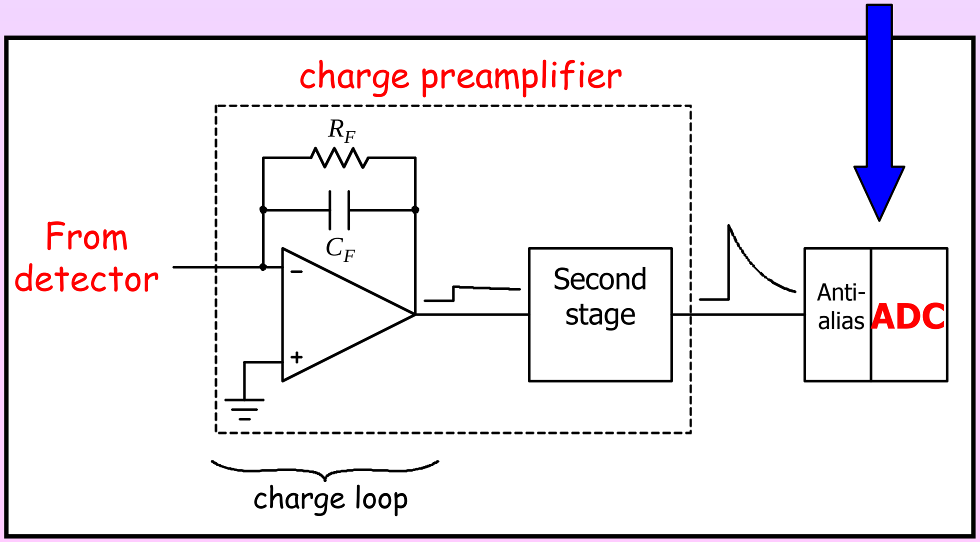
Exotic nuclei are to be disentangled in a hostile environment of high background radioactivity: (Bremsstrahlung, neutrons, charged particles…)

Background of energetic particles



The preamplifier output signals are directly digitized: shaping, filtering and pulse shape analysis are made on the digitized signals



Individual highly energetic events or bursts of piled-up events could easily cause **ADC SATURATION** and introduce a significant **SYSTEM DEAD TIME**

Mixed reset technique: continuous + pulsed

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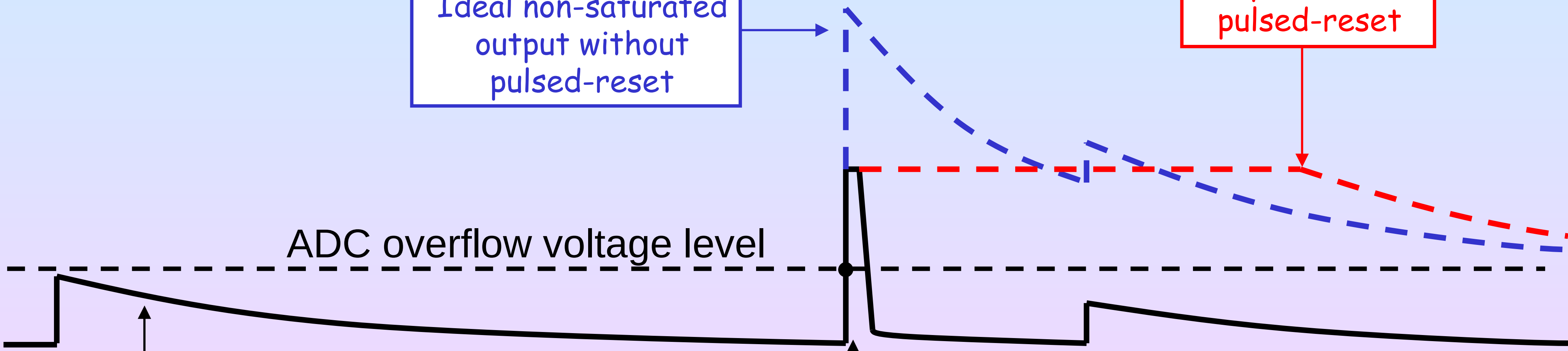


Ideal non-saturated output without pulsed-reset

Saturated output without pulsed-reset

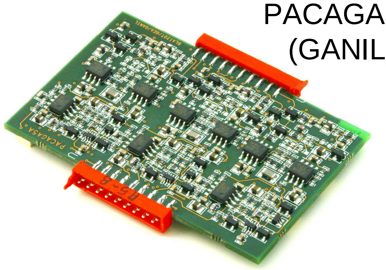
Preamplifier output with continuous-reset (50µs decay time constant)

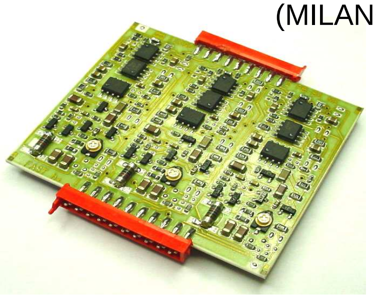
Output with pulsed-reset

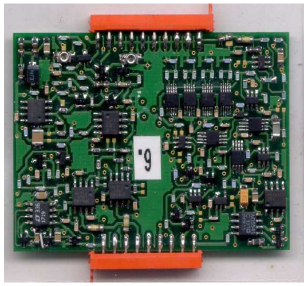
An ADC overflow condition would saturate the system for a long while

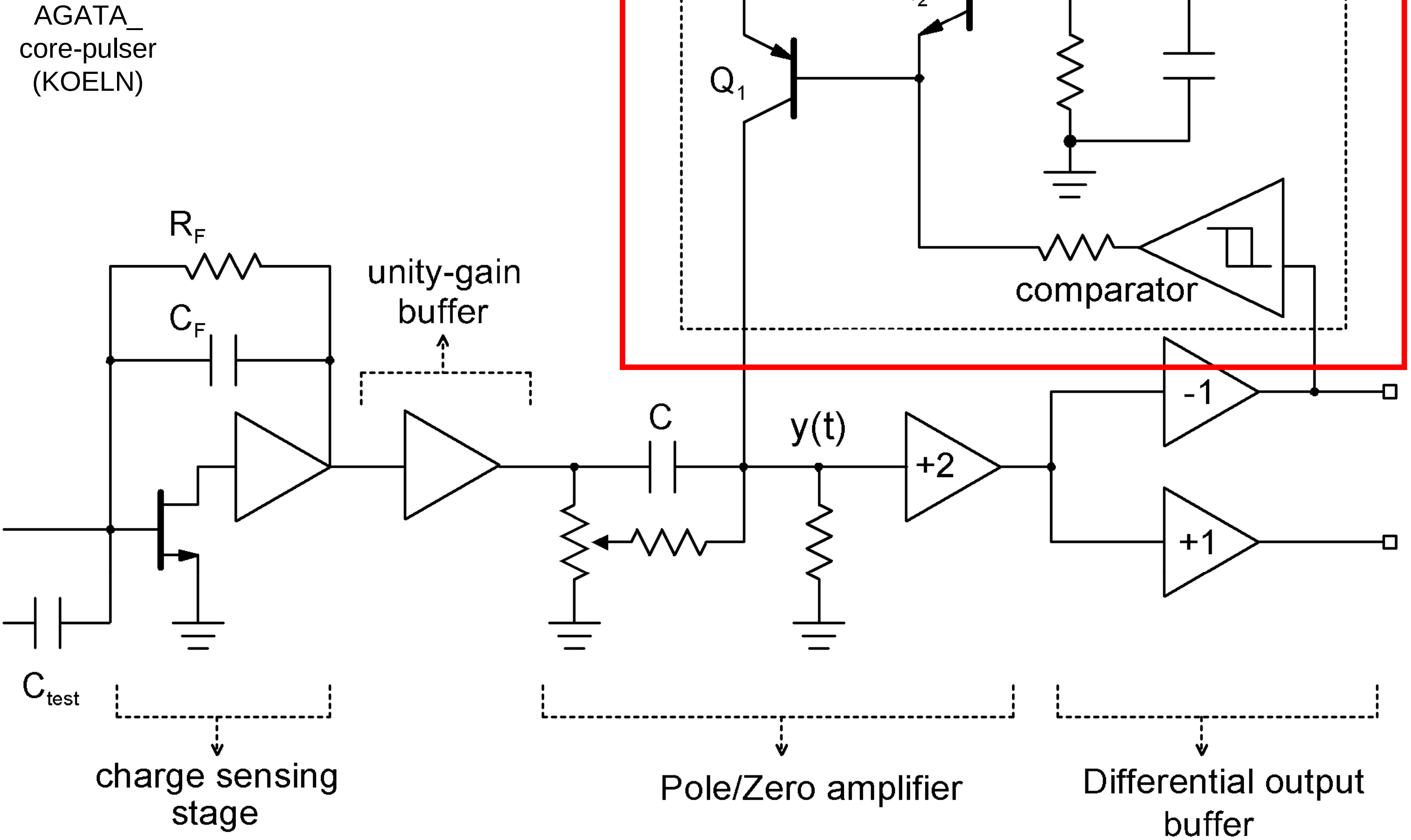
A fast-reset mechanism allows a fast recovery of the output quiescent value, so minimizing the system dead time

Fast-reset device

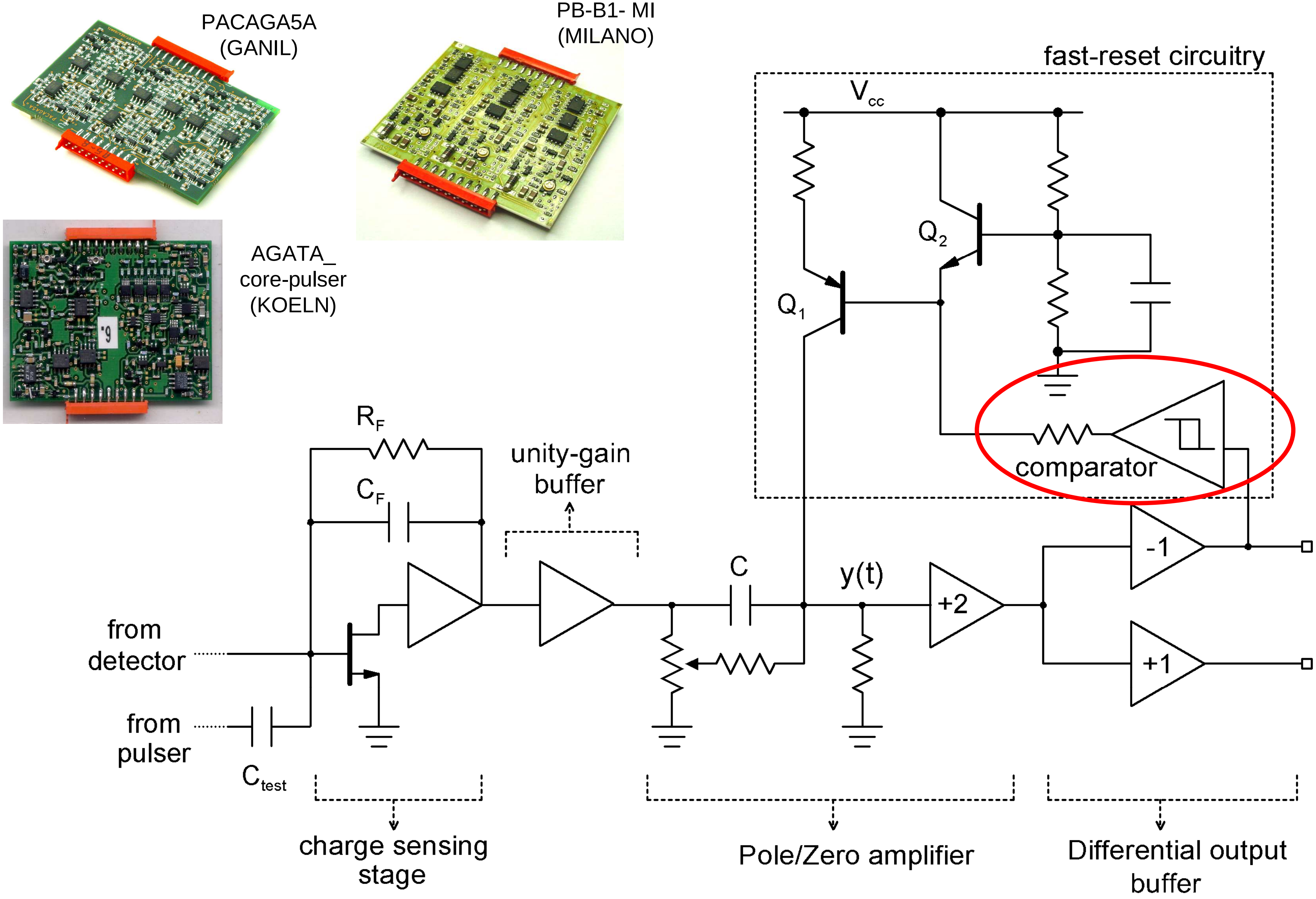

PACAGA5A
(GANIL)


PB-B1- MI
(MILANO)

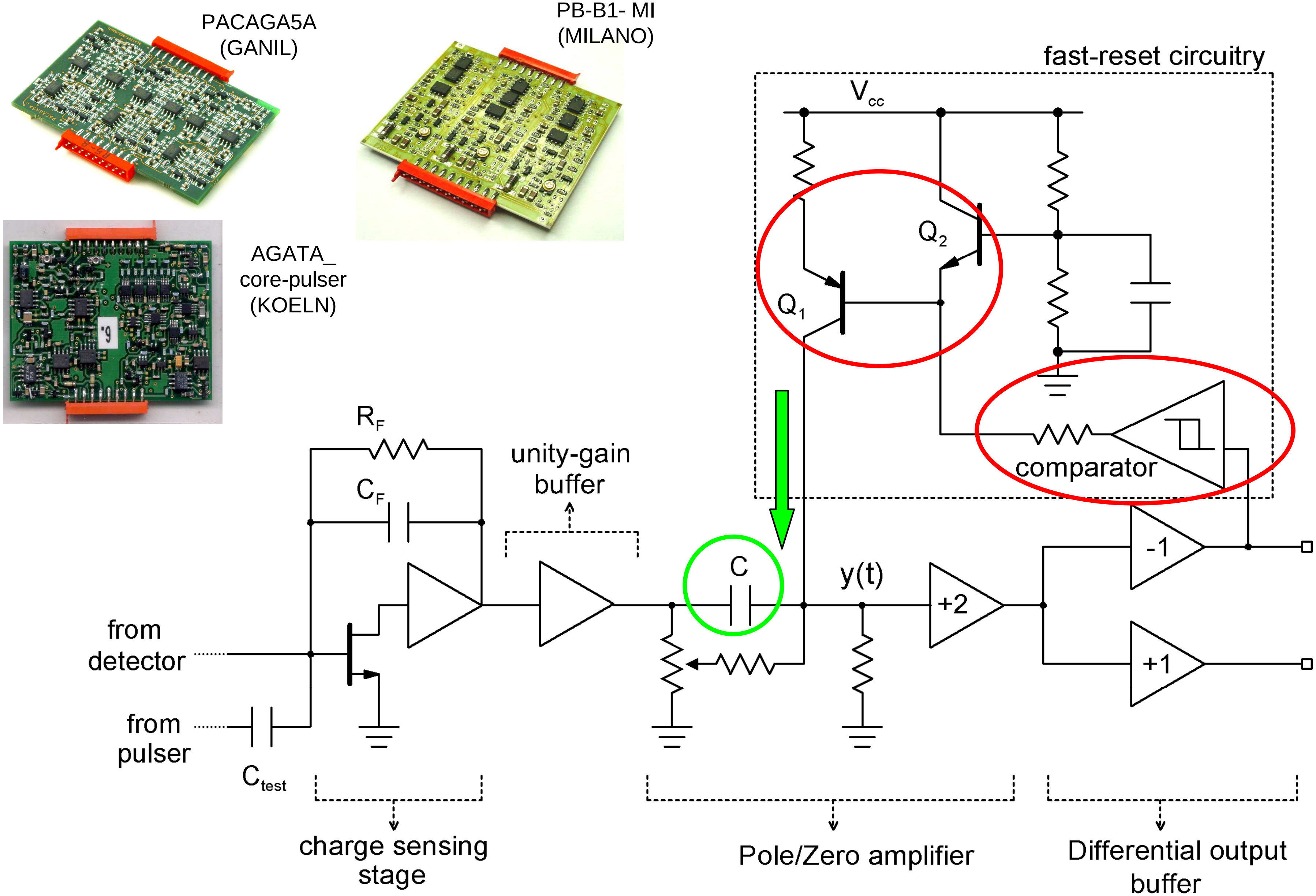

AGATA_
core-pulser
(KOELN)



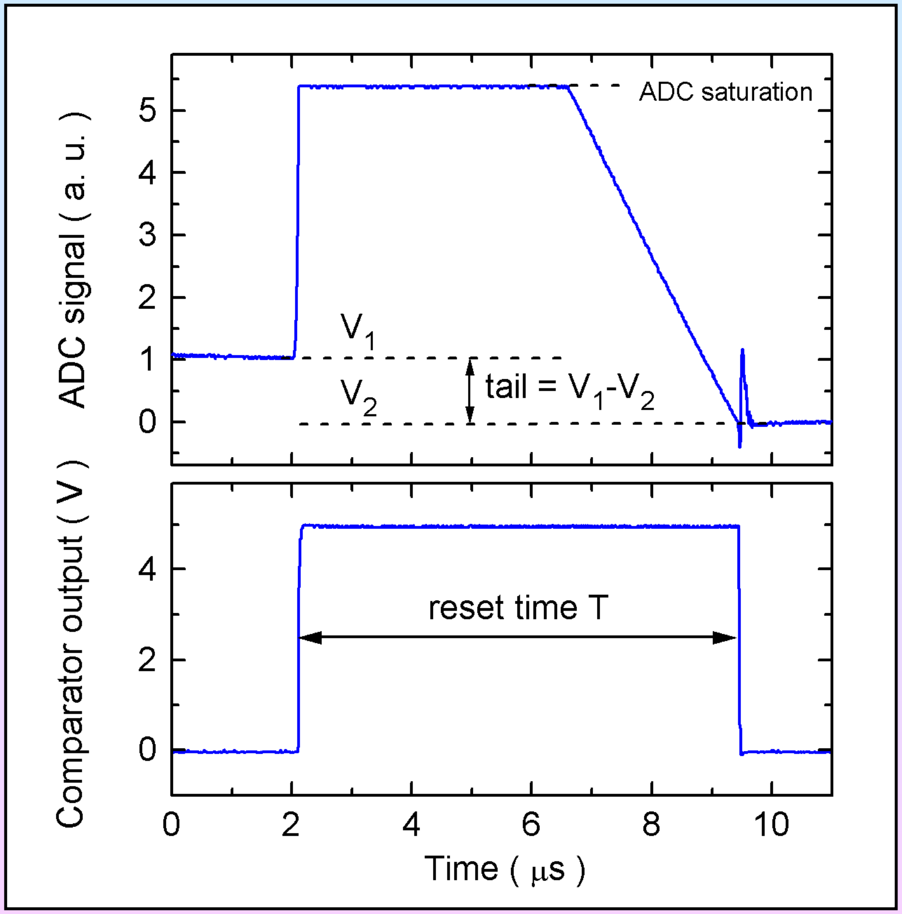
Fast-reset device



Fast-reset device



Time-Over-Threshold (TOT) technique



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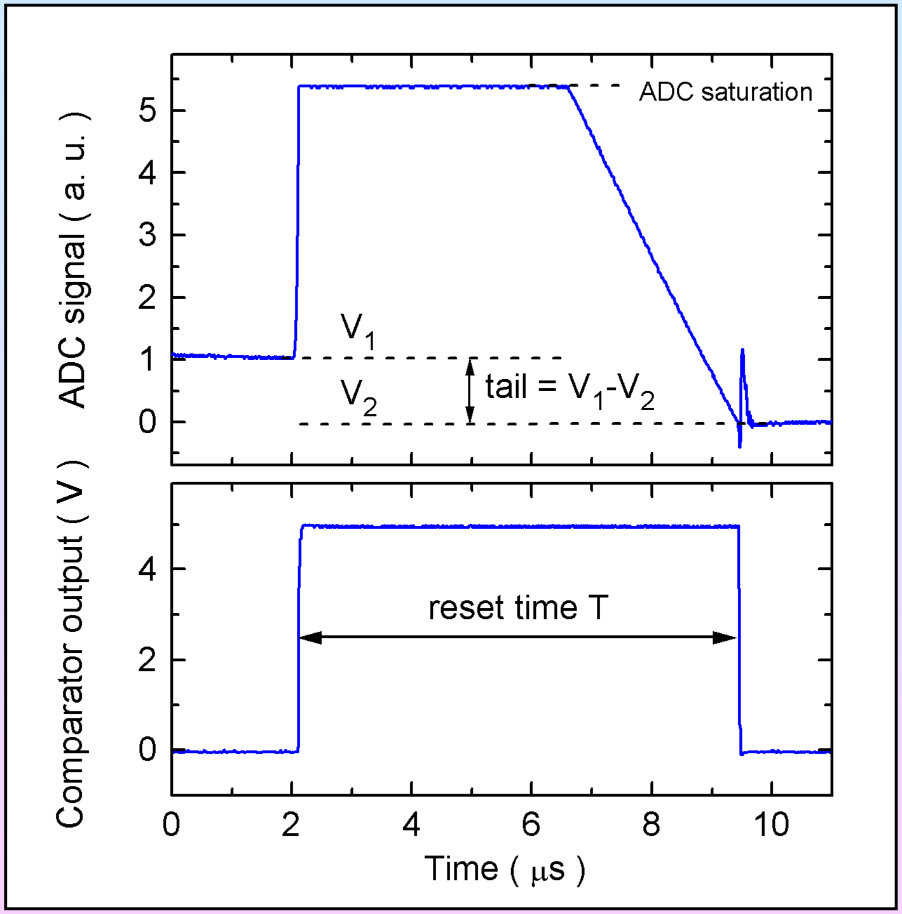
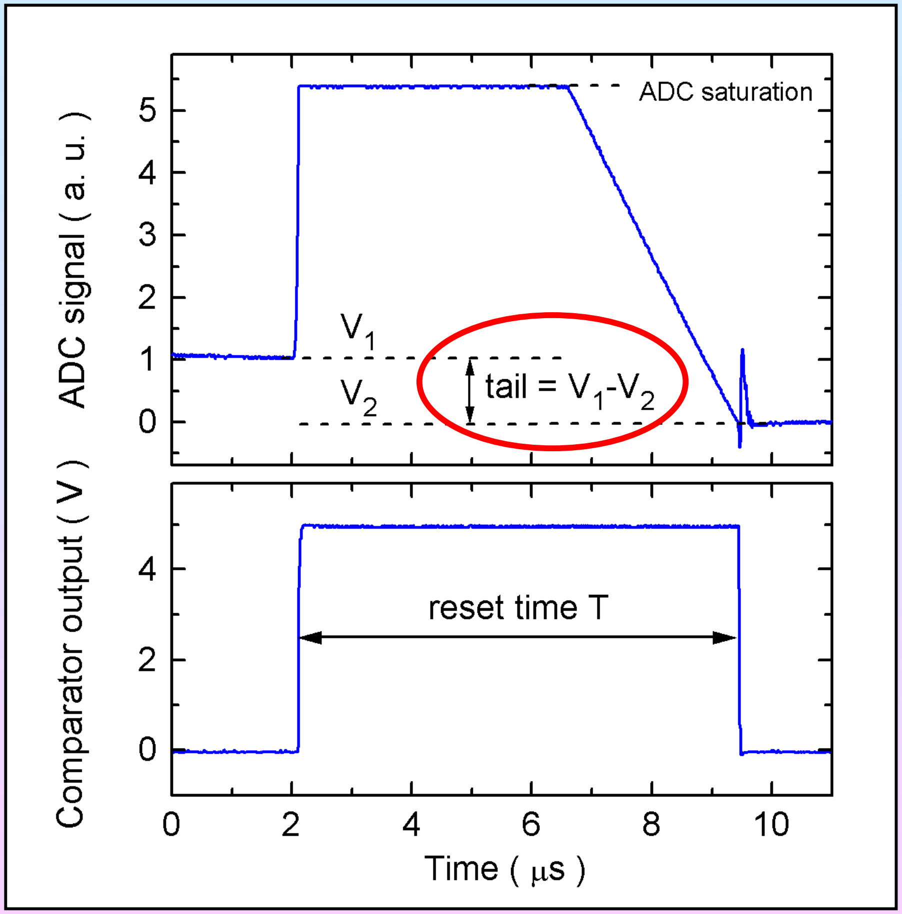


$$\boxed{E = \overbrace{b_1 T + b_2 T^2}^{\text{second-order time-energy relation}} - k_1\left(V_1 - V_2\right) + \overbrace{E_O}^{\text{offset term}}}$$

***E* = energy of the large signal**

***T* = reset time**

Time-Over-Threshold (TOT) technique



$$\boxed{E = \overbrace{b_1 T + b_2 T^2}^{\text{second-order time-energy relation}} \underbrace{- k_1 \left(V_1 - V_2\right)}_{\text{contribution of the tail due to previous events}} + \overbrace{E_O}^{\text{offset term}}}$$

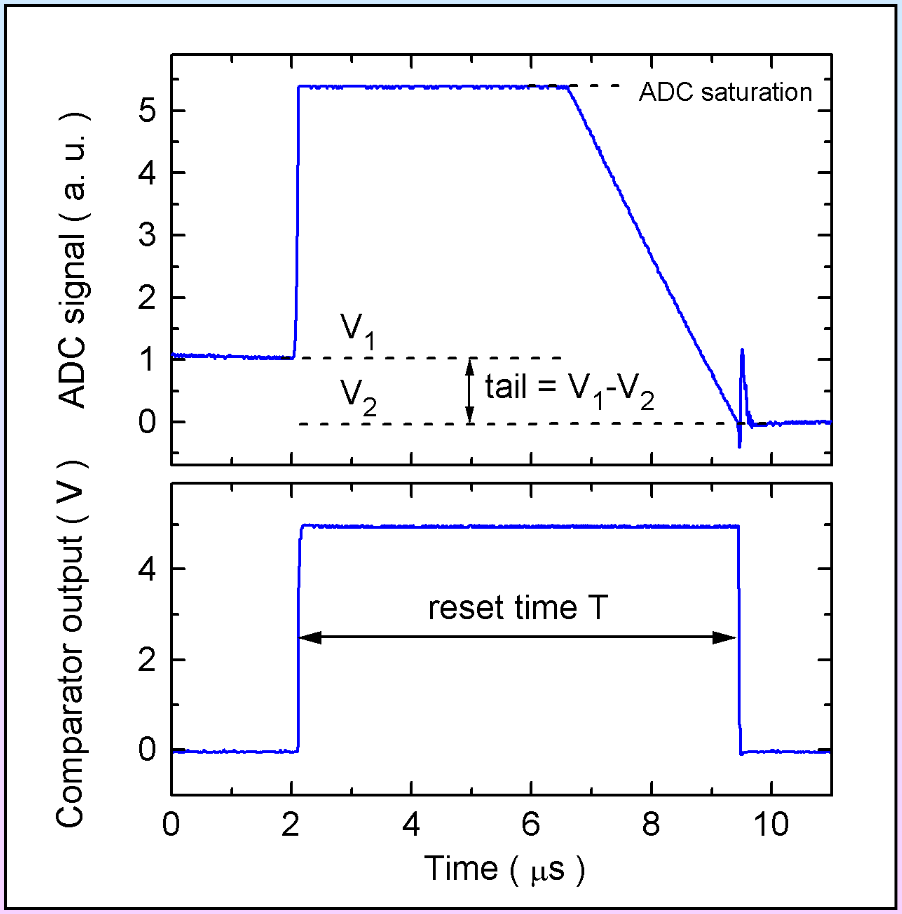
E = *energy of the large signal*

T = *reset time*

V_1, V_2 = *pre-pulse and post-pulse baselines*

b_1, b_2, k_1, E_0 = *fitting parameters*

Time-Over-Threshold (TOT) technique



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E = energy of the large signal

T = reset time

V_1, V_2 = pre-pulse and post-pulse baselines

b_1, b_2, k_1, E_0 = fitting parameters

Within ADC range → standard "pulse-height mode" spectroscopy

Beyond ADC range → new "reset mode" spectroscopy

Experimental setup with the AGATA capsule

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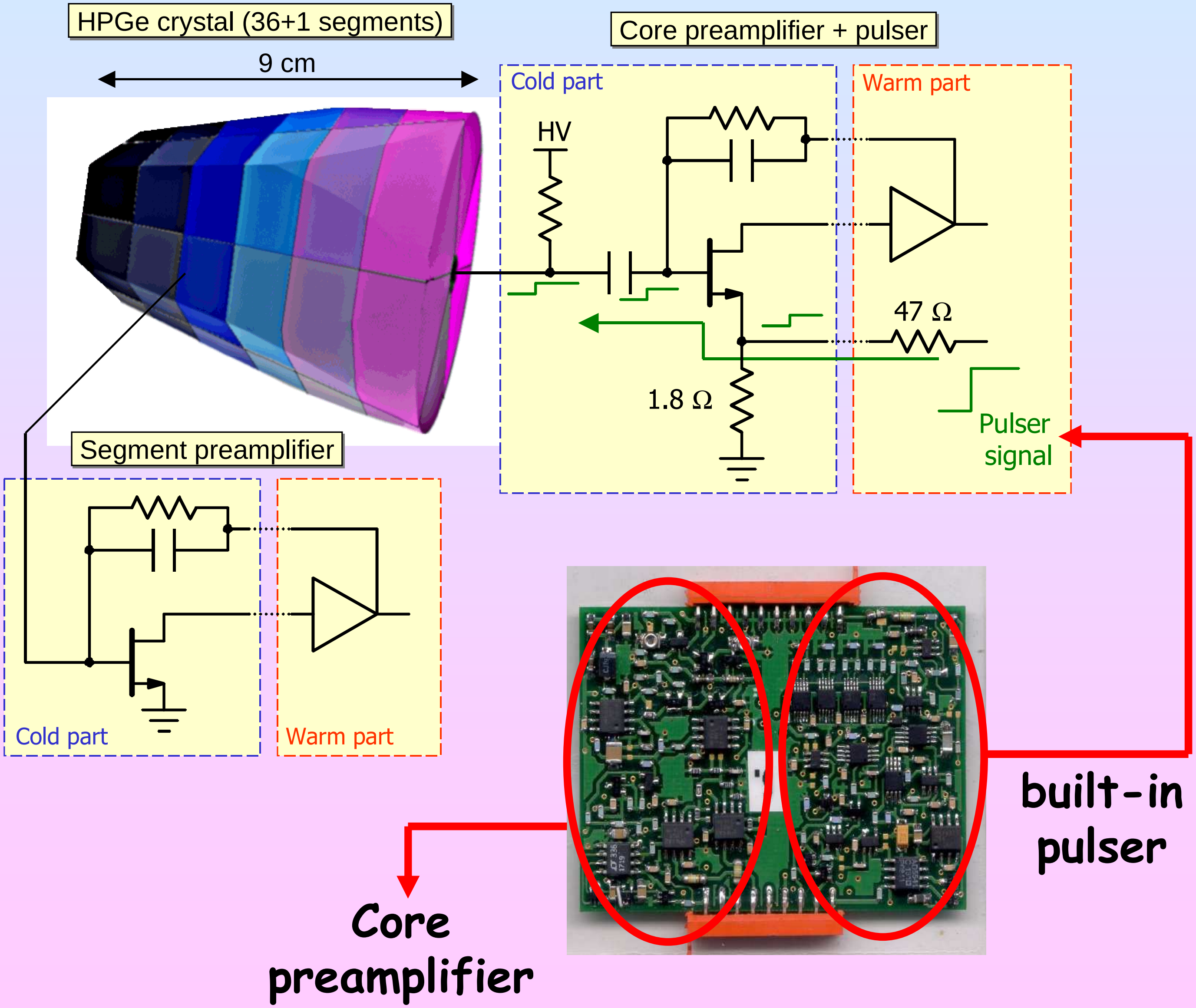
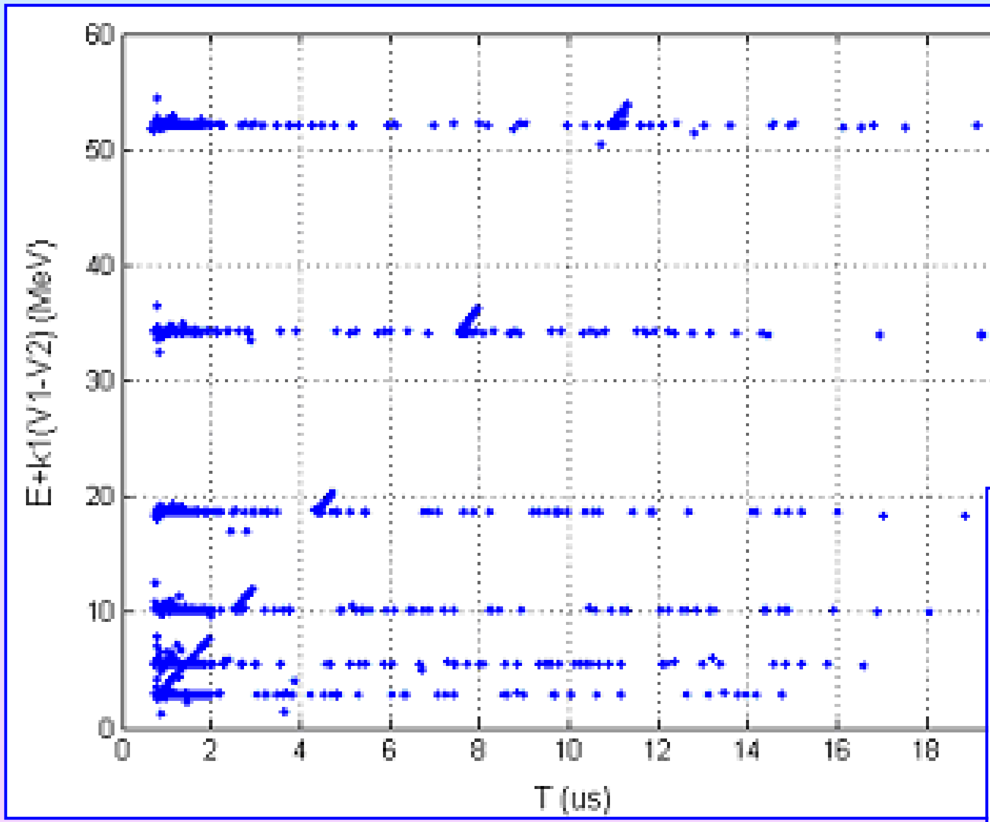
Encapsulated AGATA HPGe crystal at LNL



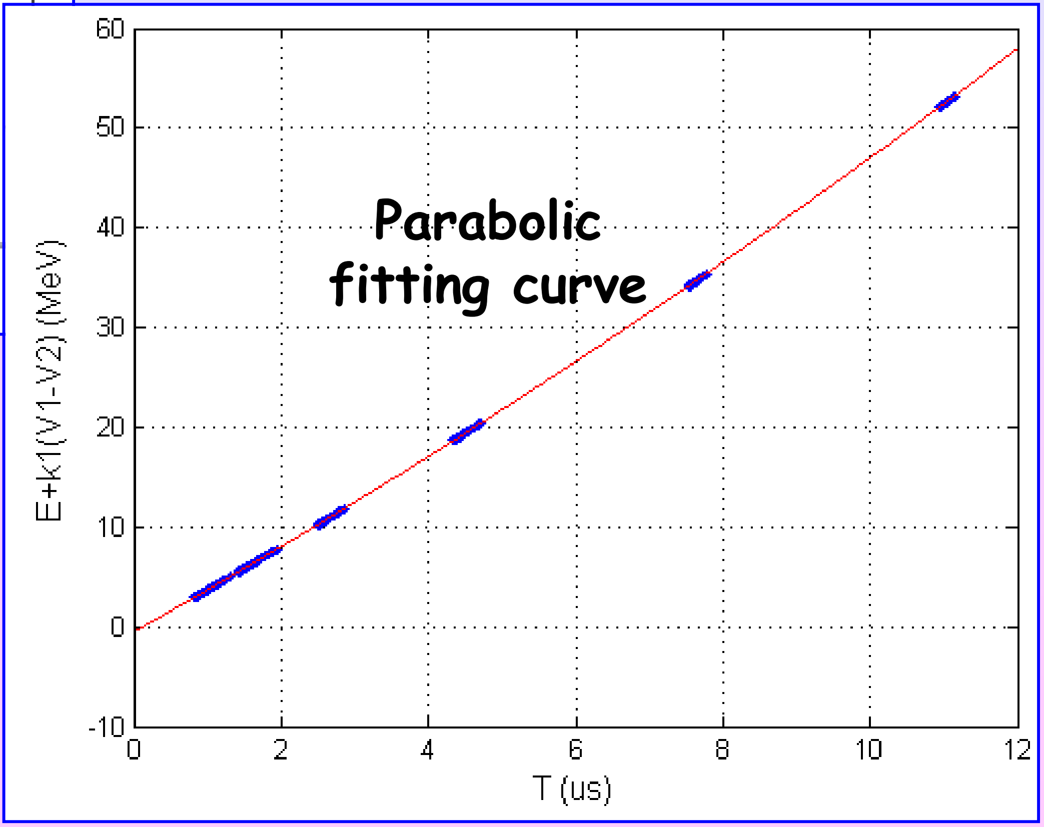
Calibration procedure



$$E + k_1\left(V_1 - V_2\right) = b_1 T + b_2 T^2 + E_O$$

Parameters calculated by a fitting procedure

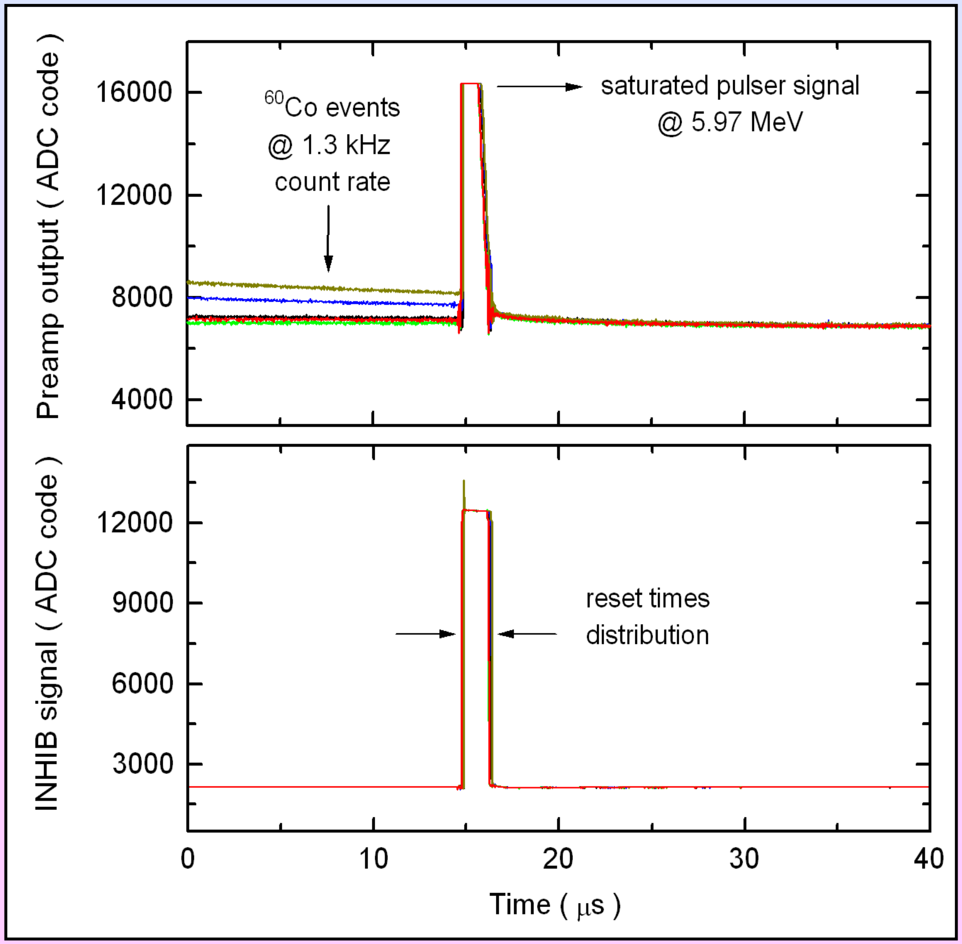
Calibration pulser signals are completely disentangled from the background



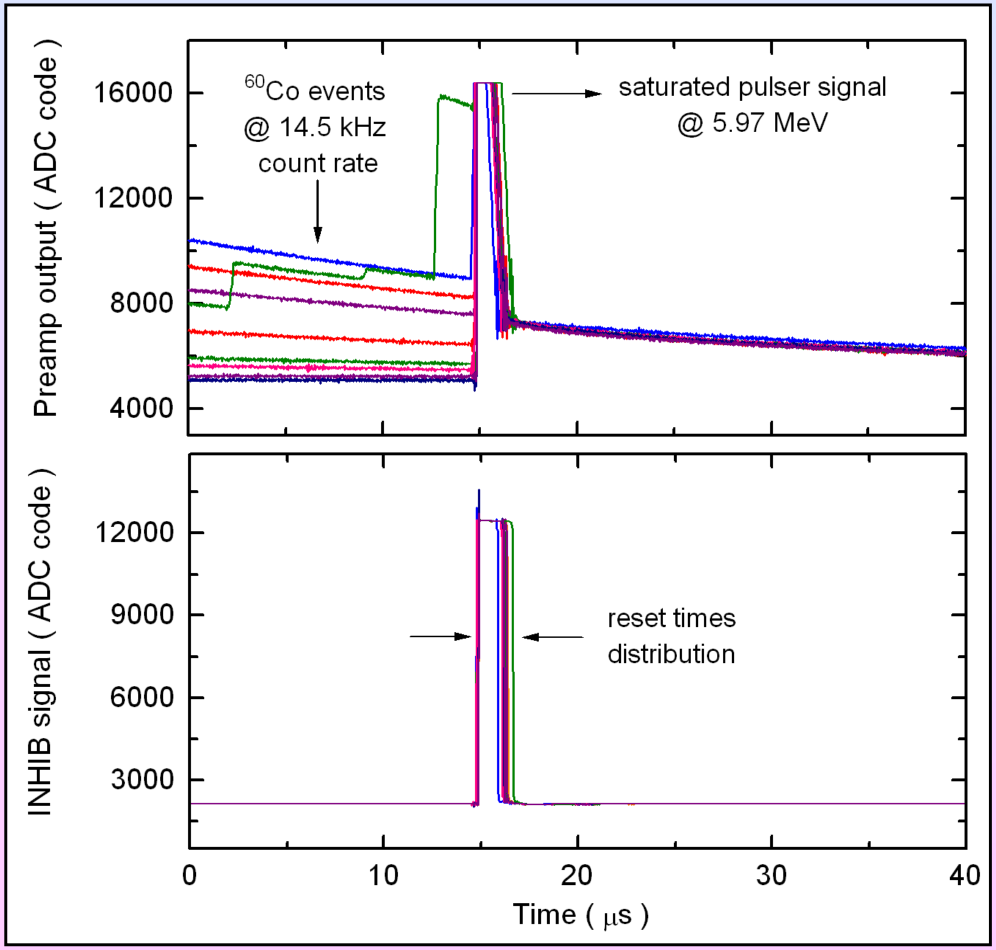
TOT technique applied to over-threshold pulser signals (1)

Pulser signal @ 5.97 MeV

^{60}Co background rate = 1.3 kHz

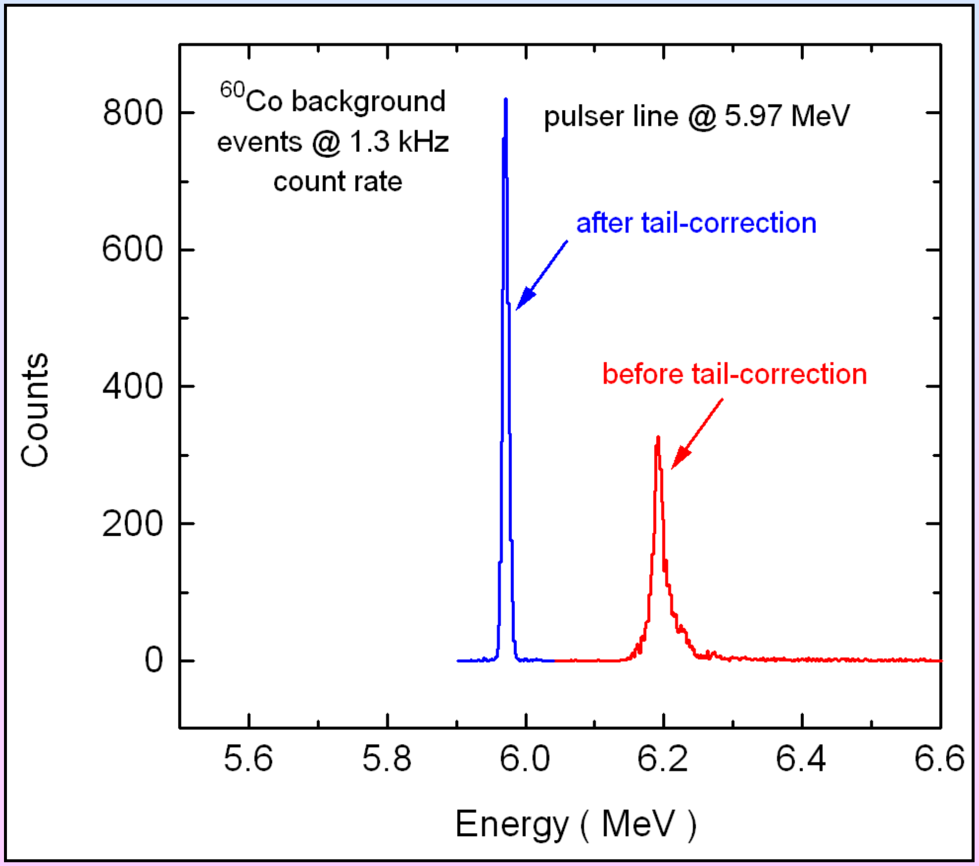


^{60}Co background rate = 14.5 kHz

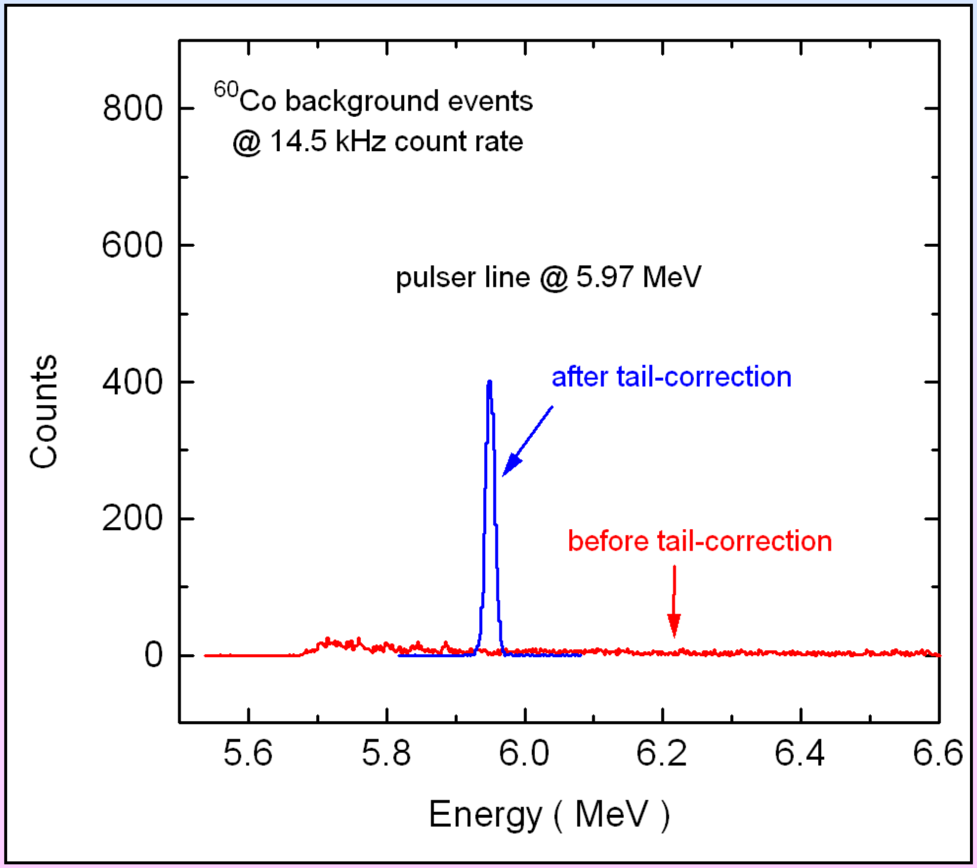


TOT technique applied to over-threshold pulser signals (2)

^{60}Co background rate = 1.3 kHz



^{60}Co background rate = 14.5 kHz



Resolution @ 5.97 MeV =
10.5 keV (0.18 %)

Resolution @ 5.97 MeV=
15.2 keV (0.25 %)

TOT technique applied to over-threshold pulser signals (3)

Background event rate = 800 Hz

Pulser line energy	Resolution (fwhm)	
E_1 = 3.3501 MeV	11.68 keV	0.35 %
E_2 = 5.9720 MeV	11.42 keV	0.19 %
E_3 = 10.656 MeV	11.28 keV	0.11 %
E_4 = 18.797 MeV	12.55 keV	0.067 %
E_5 = 33.369 MeV	14.33 keV	0.043 %
E_6 = 49.434 MeV	19.16 keV	0.039 %

Better than 0.4%
over the full range

Pulser energy = 5.97 MeV

Event rate	Resolution (fwhm)	
1.3 kHz	10.50 keV	0.18 %
2.3 kHz	11.79 keV	0.20 %
4.2 kHz	12.57 keV	0.21 %
8.2 kHz	13.23 keV	0.22 %
14.5 kHz	15.18 keV	0.25 %

Pulser energy = 10.65 MeV

Event rate	Resolution (fwhm)	
1.2 kHz	12.07 keV	0.11 %
2.4 kHz	12.97 keV	0.12 %
4.2 kHz	14.02 keV	0.13 %
8.2 kHz	17.87 keV	0.17 %
14.5 kHz	22.56 keV	0.21 %

Pulser energy = 18.8 MeV

Event rate	Resolution (fwhm)	
1.3 kHz	12.94 keV	0.069 %
2.3 kHz	15.56 keV	0.083 %
4.2 kHz	18.64 keV	0.10 %
8.2 kHz	~ 30 keV	0.16 %
14.2 kHz	~ 40 keV	0.21 %

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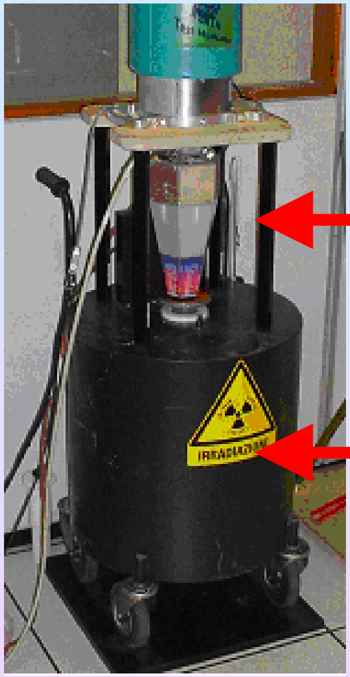
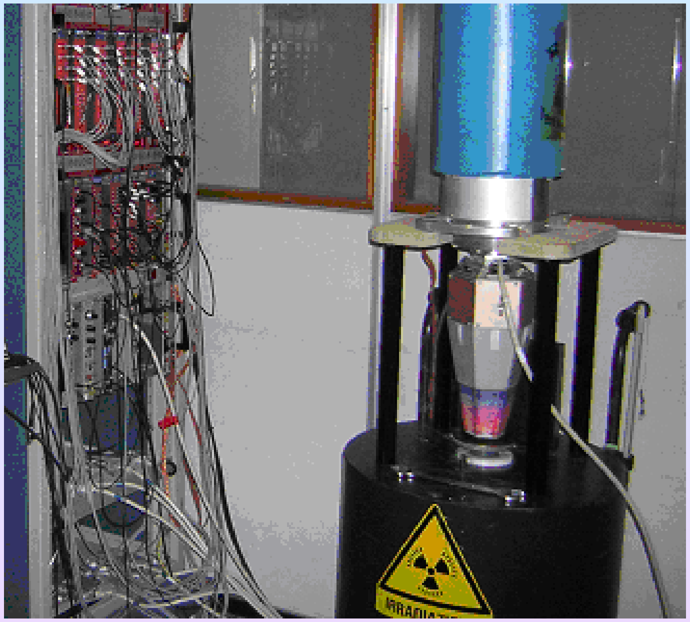
Obtained resolutions better than 0.25% for all the tested count rates

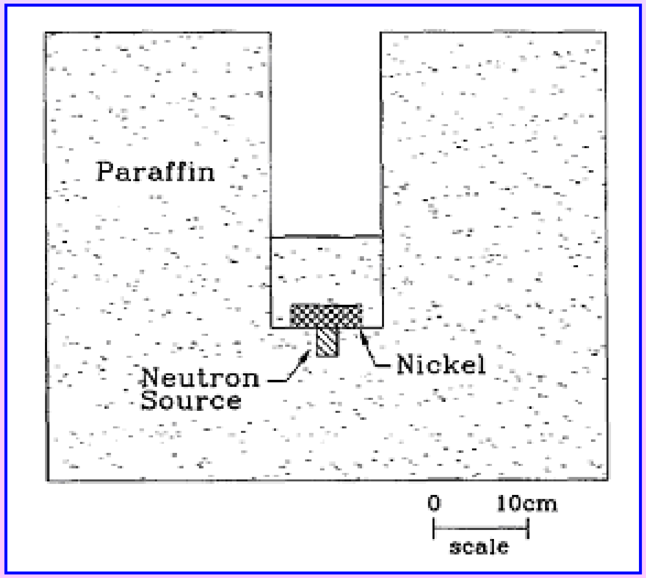
Experimental setup: ^{241}Am+Be source



AGATA capsule
at LNL

^{241}Am+Be source
with Ni target

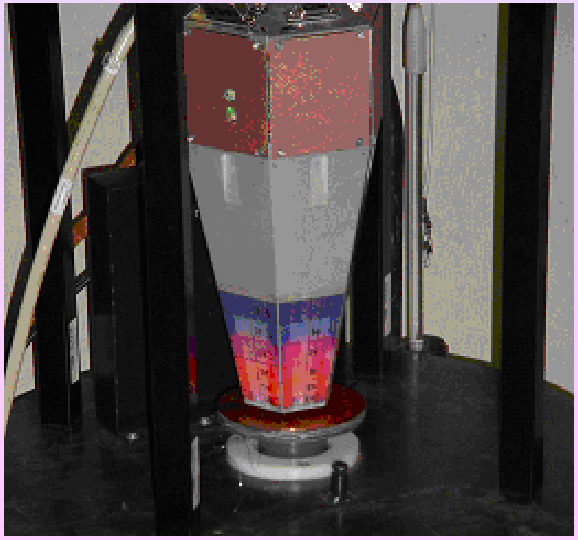




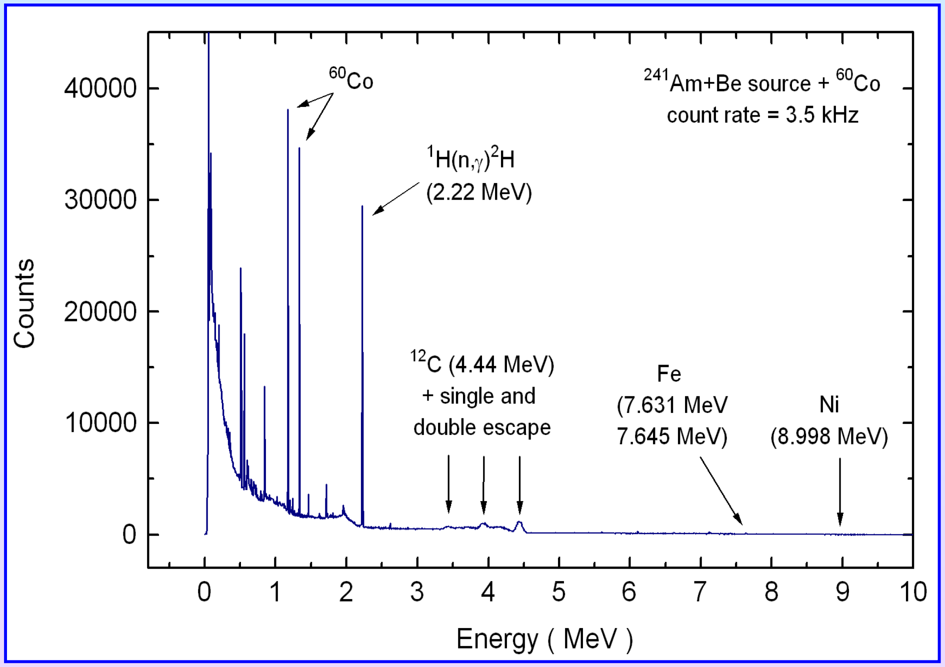
Fast neutrons thermalized in paraffin and captured by natural metallic nickel

↓

γ-photons produced in the 4 to 9 MeV range

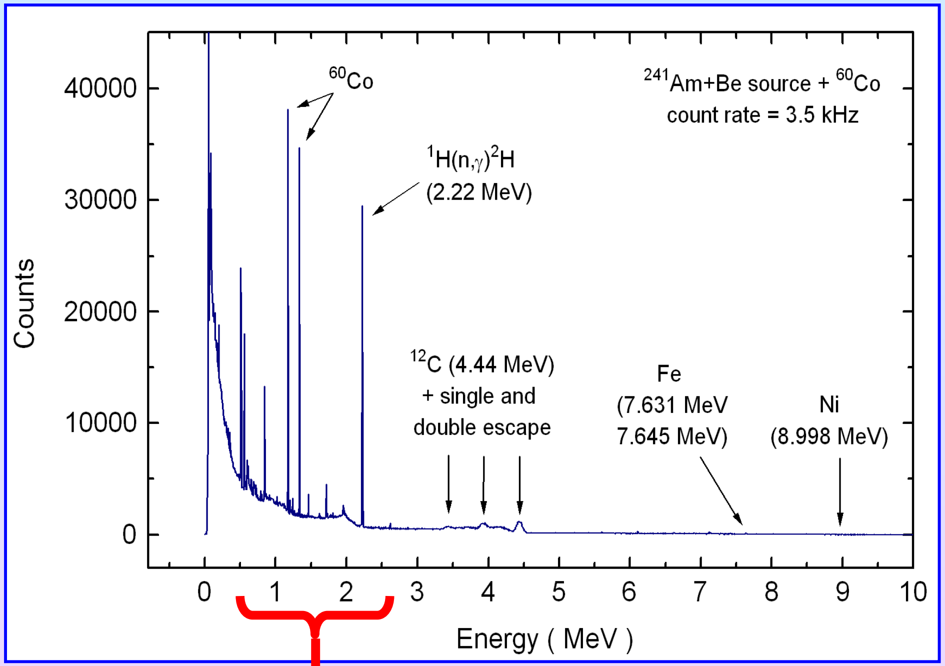


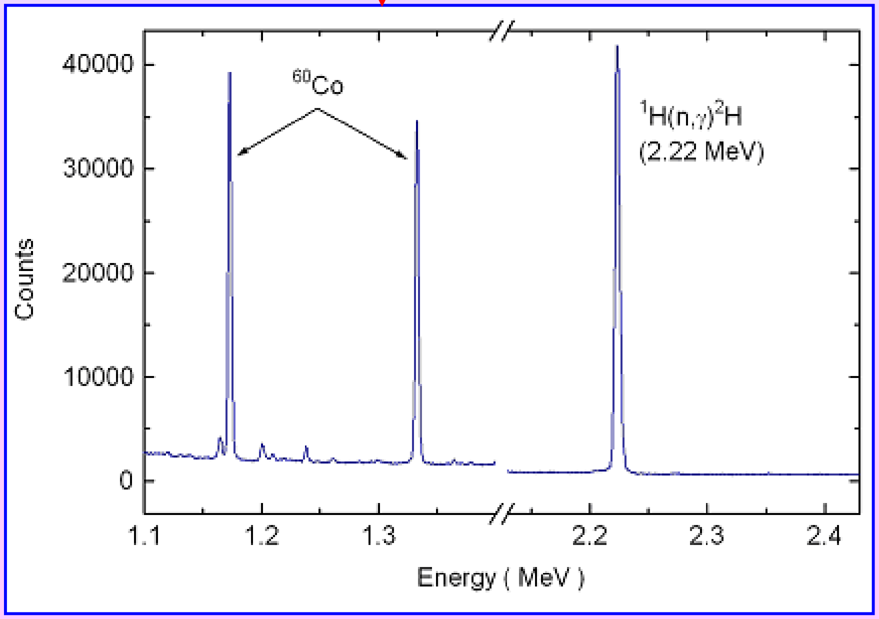
^{241}Am+Be spectrum in pulse-height mode



Energy	Resolution (fwhm) in “pulse-height” mode	
1.1732 MeV (^{60}Co)	2.99 keV	0.25 %
1.3325 MeV (^{60}Co)	3.24 keV	0.24 %
2.2233 MeV (H)	4.51 keV	0.20 %
4.440 MeV (^{12}C)	104 keV	2.34 %
7.6312 MeV (Fe)	11 keV	0.14 %
7.6456 MeV (Fe)	11 keV	0.14 %
8.9984 MeV (Ni)	15 keV	0.17 %

^{241}Am+Be spectrum in pulse-height mode





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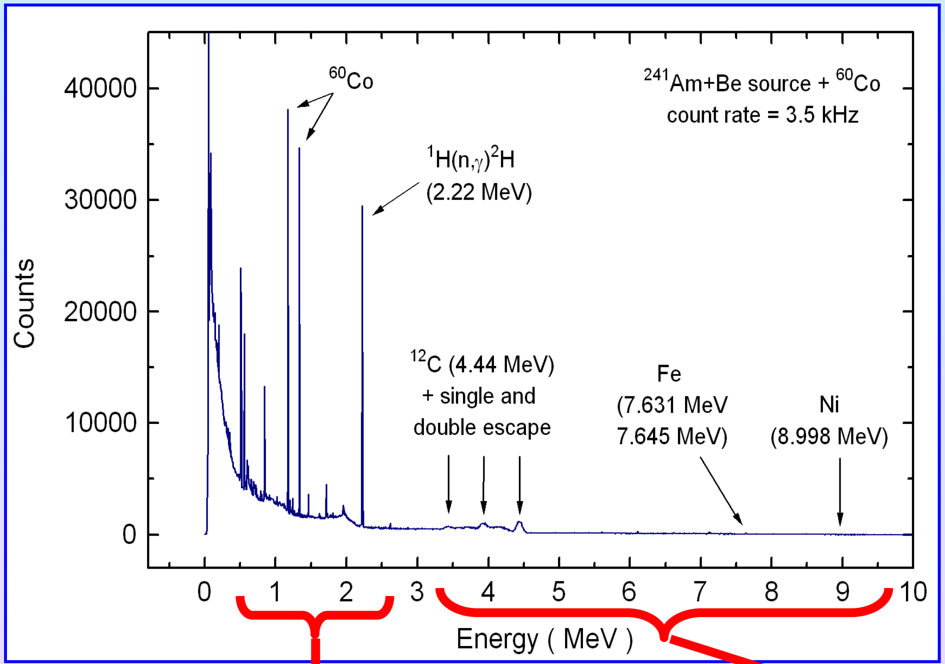
^{241}Am+Be spectrum in pulse-height mode



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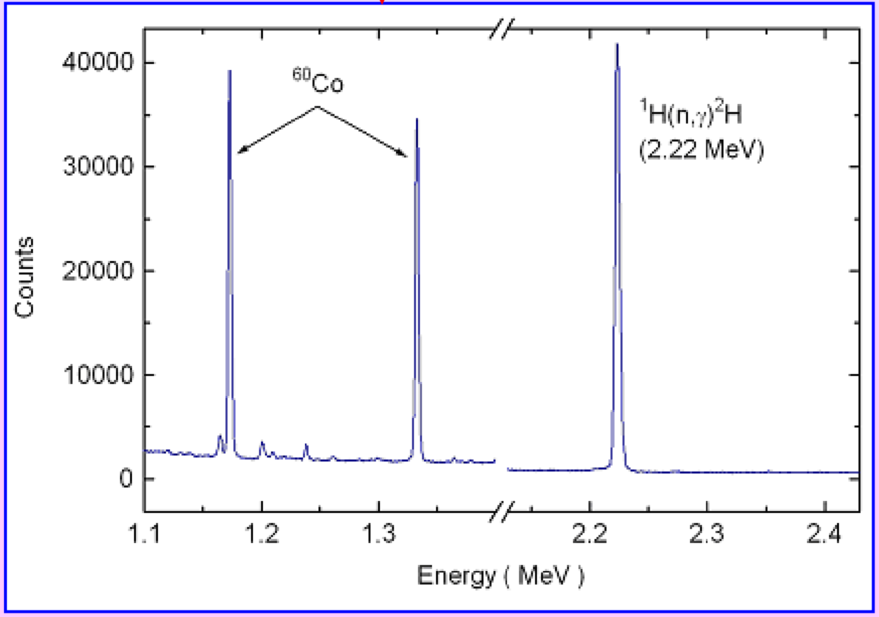
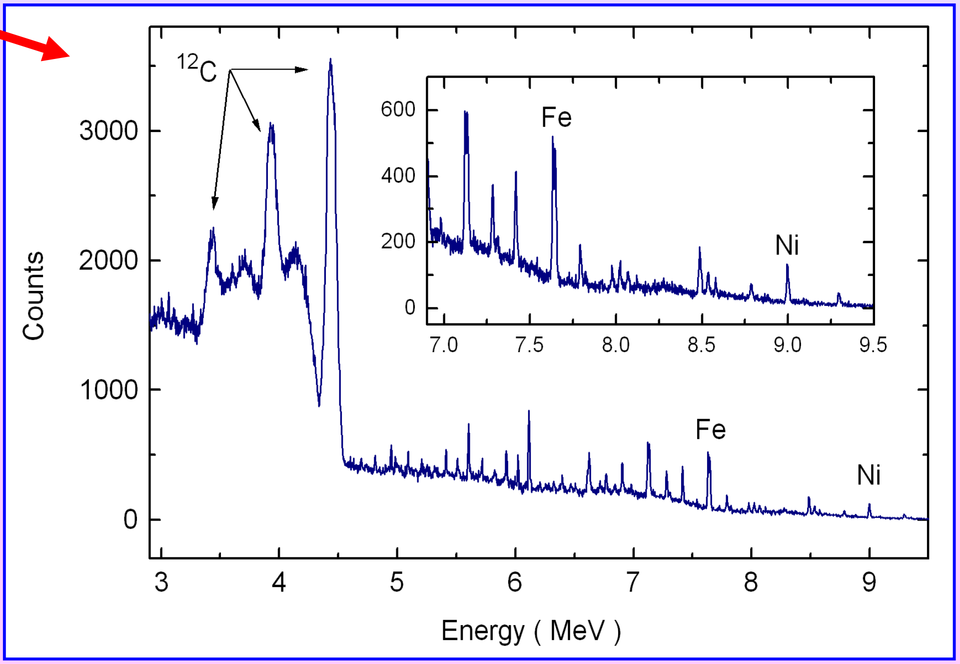
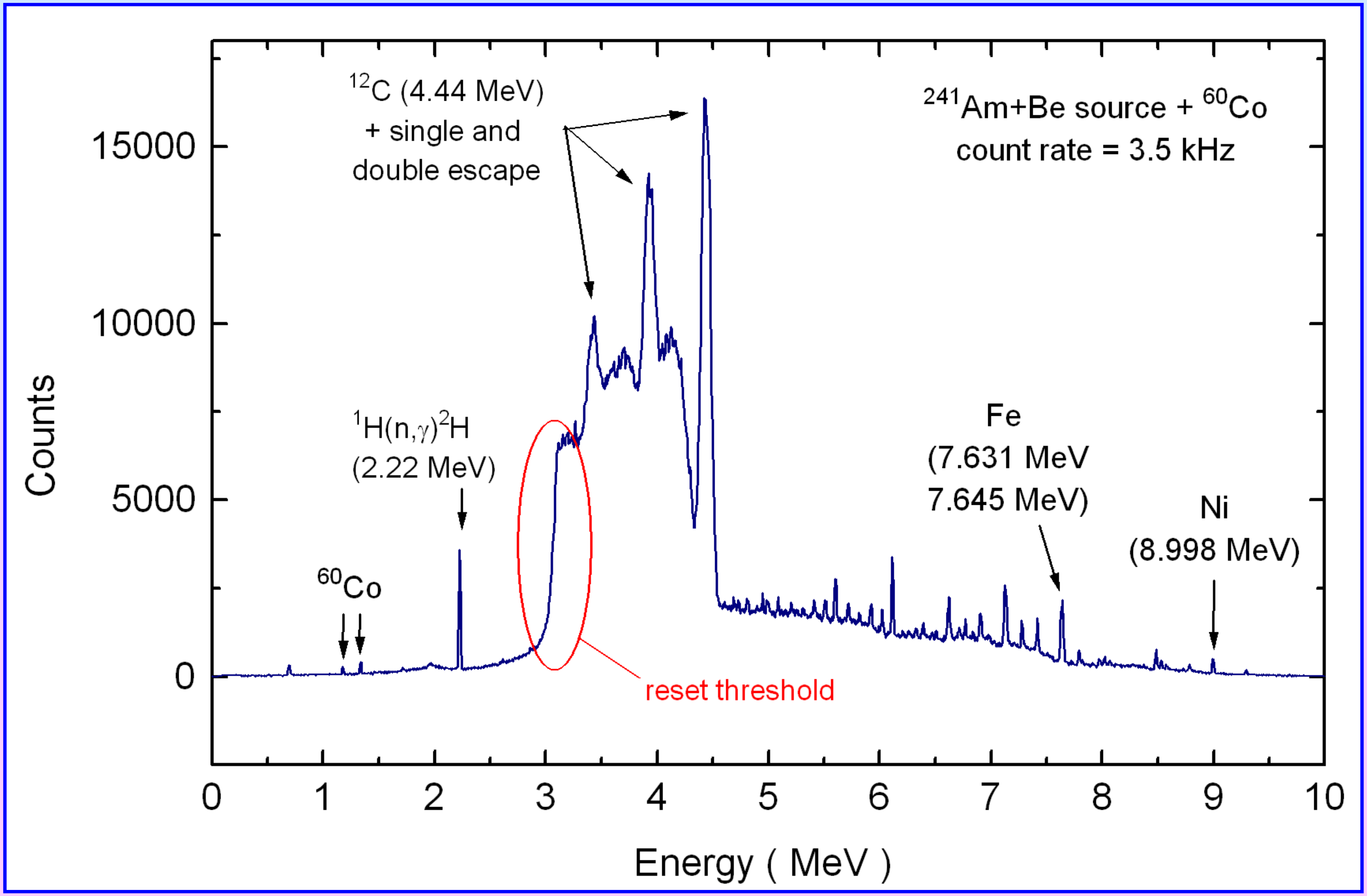


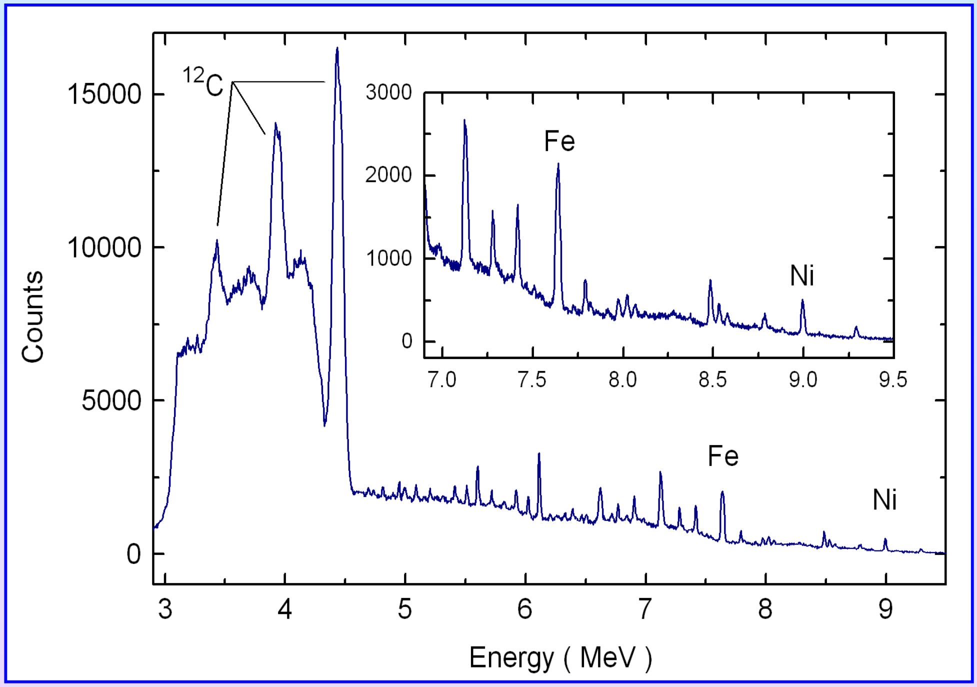


^{241}Am+Be spectrum in reset mode



^{241}Am+Be spectrum

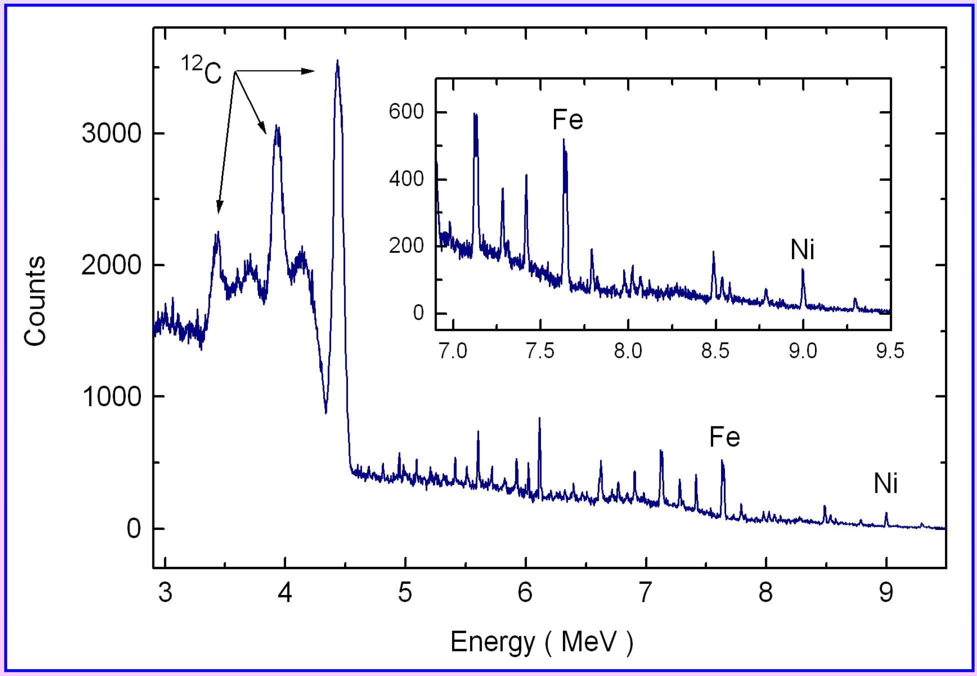
EURONS



"reset" mode

(by TOT technique)

Energy	Resolution (fwhm) in pulse-height mode		Resolution (fwhm) in reset mode	
4.440 MeV (^{12}C)	104 keV	2.34 %	104 keV	2.34 %
~5.6 MeV	10.5 keV	0.14 %	18.8 keV	0.34 %
~6.1 MeV	15.1 keV	0.17 %	17.1 keV	0.28 %
7.6312 MeV (Fe)	11 keV	0.14 %	18.8 keV (29.4 keV for the double-peak)	0.25 % (0.38 % for the double-peak)
7.6456 MeV (Fe)	11 keV	0.14 %		
8.9984 MeV (Ni)	15 keV	0.17 %	18.9 keV	0.21 %



"pulse-height" mode

(by ADC)

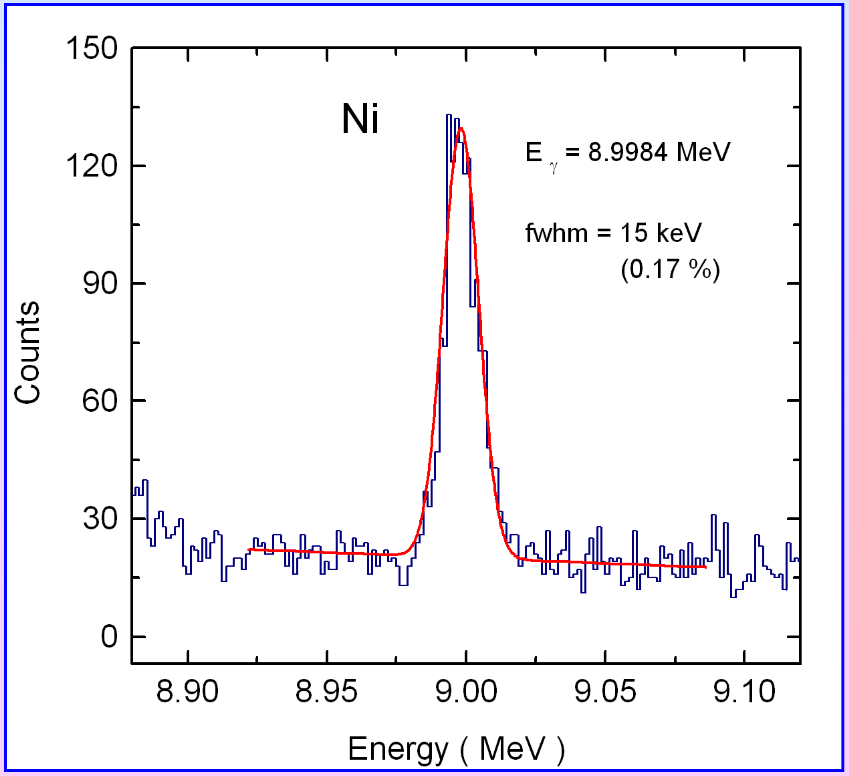
Comparison on the 8.99 MeV Ni line

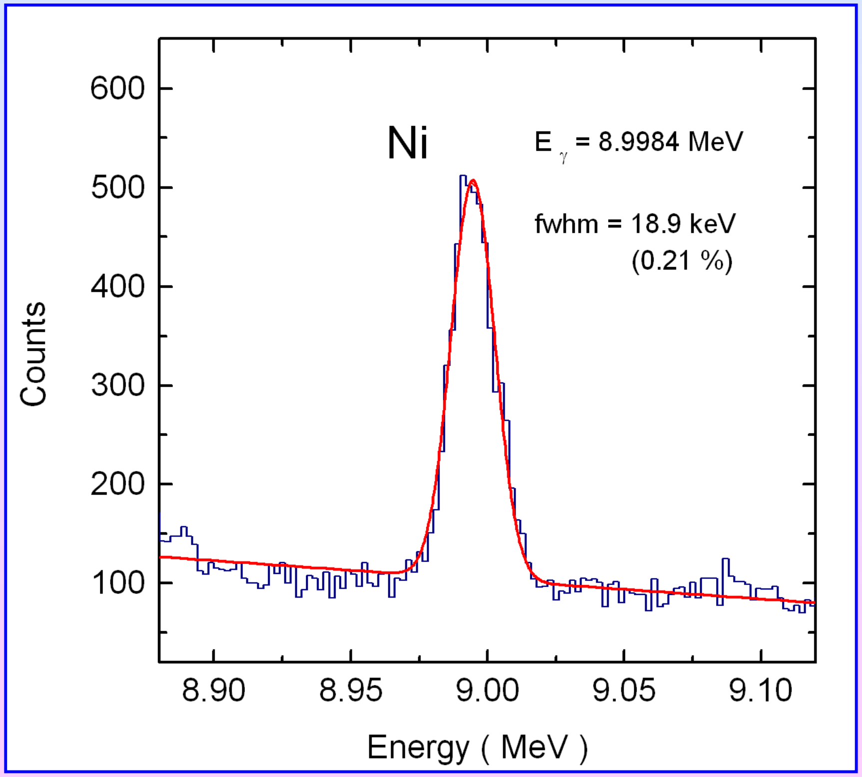
"pulse-height" mode

FWHM = 15 keV (0.17 %)

"reset" mode

FWHM = 19 keV (0.21 %)





At high energies the performance in reset mode approaches the performance in pulse-height mode

The ideal acquisition chain: "dual-range" core preamplifier

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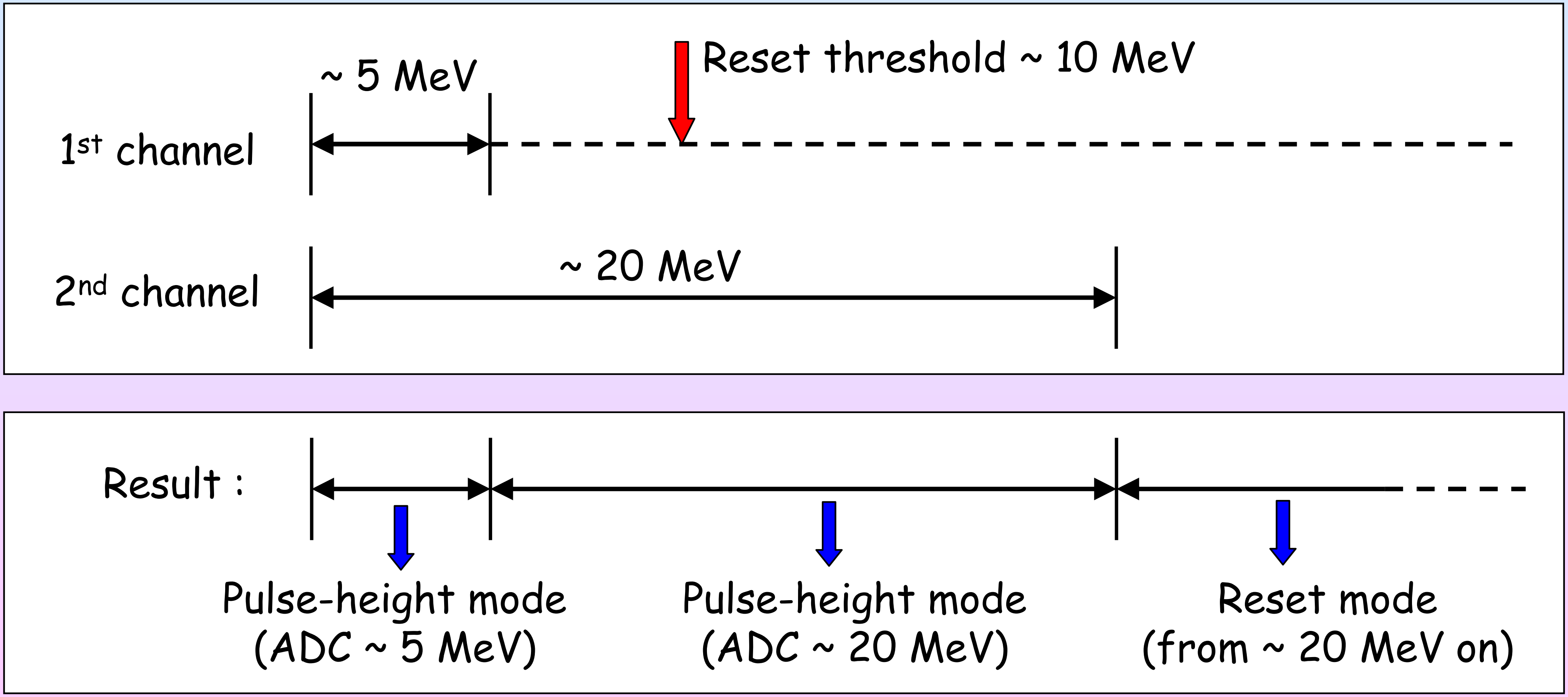
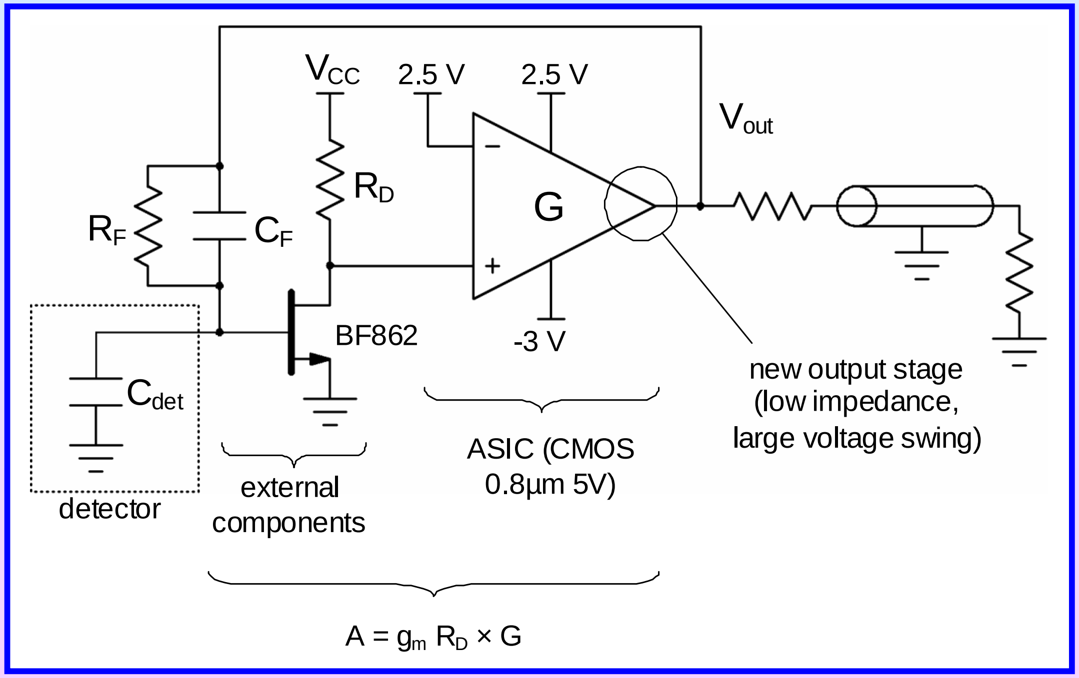


First results with an ASIC preamplifier for Ge detectors

The realized JFET-CMOS preamplifier

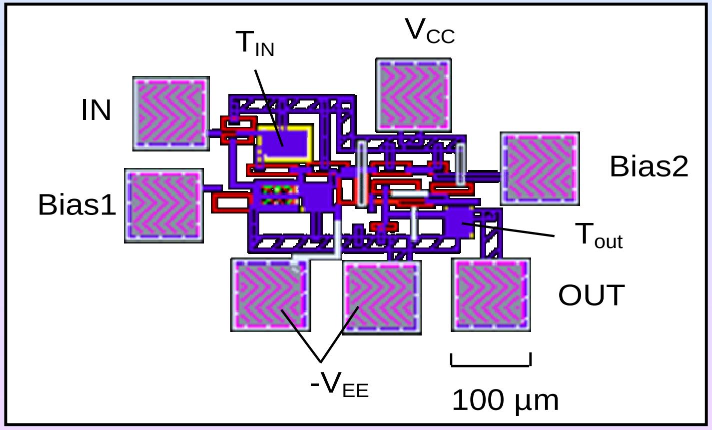
DC-coupled, optimized for negative signals (hole signals),
fully functional at cryogenic temperature

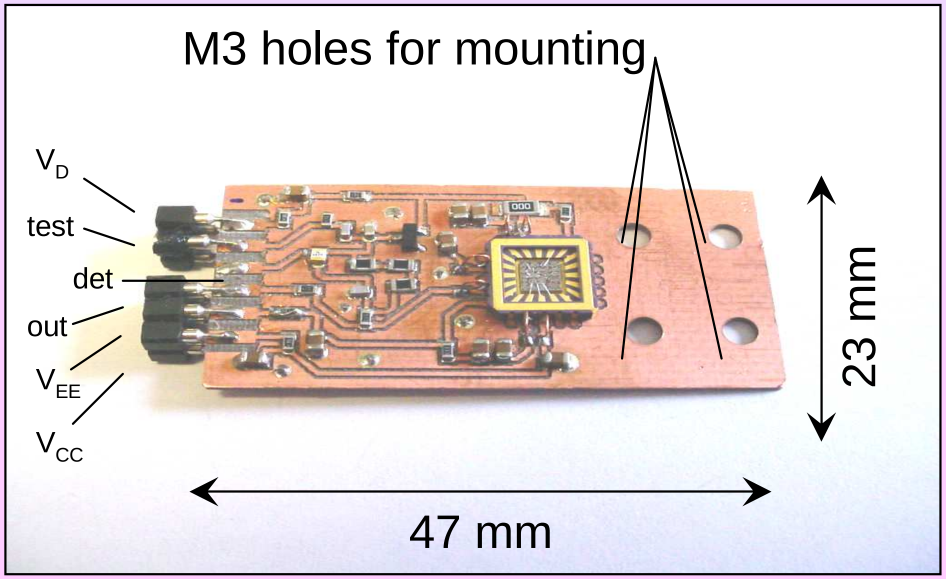


Inspired to that proposed in : J. Gal et al. “Realization of charge sensitive preamplifiers using current feedback operational amplifier”, Nucl. Instrum. And Meth., Vol. A366, pp. 145-147, 1995

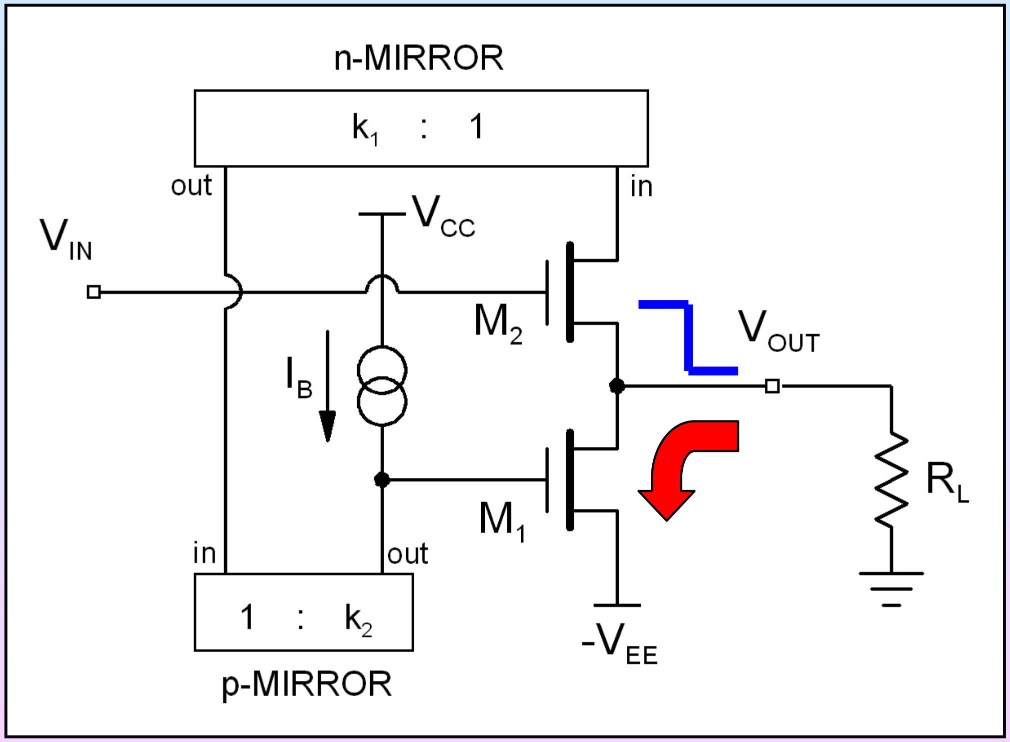
Integrated circuit and discrete devices as mounted on a Printed Circuit Board of 0.8 mm teflon (PTFE) laminate

5V 0.8µm CMOS technology provided by Austria Micro Systems





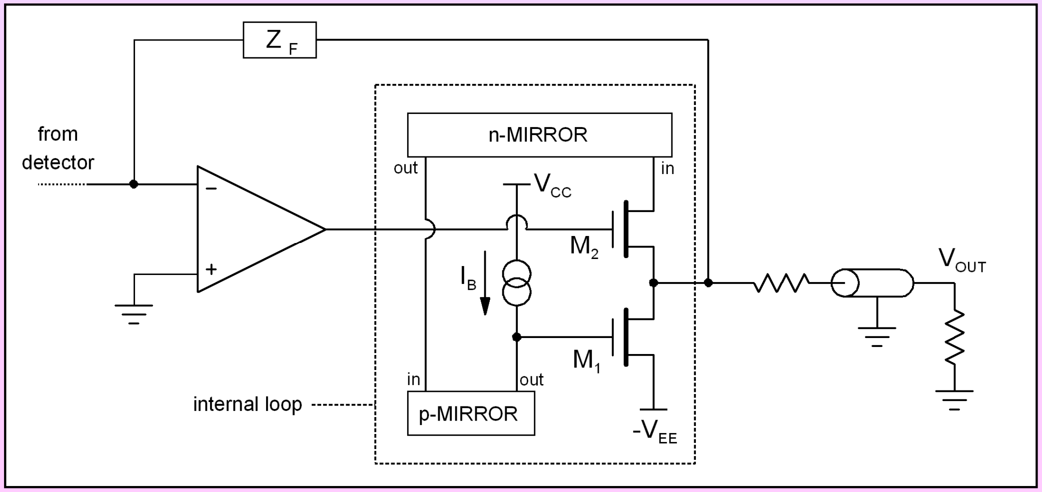
The proposed CMOS output stage: a self-adjusting constant-current source follower



M_2 (n-MOS) is the **"source-follower"** transistor, whose current is kept constant by the negative feedback loop

M_1 (n-MOS) acts as a **"driver"** transistor, and provides the load current whenever a negative output signal is present

Inserted into the loop of a negative feedback amplifier to guarantee the best overall circuit linearity (mandatory for gamma-ray spectroscopy)



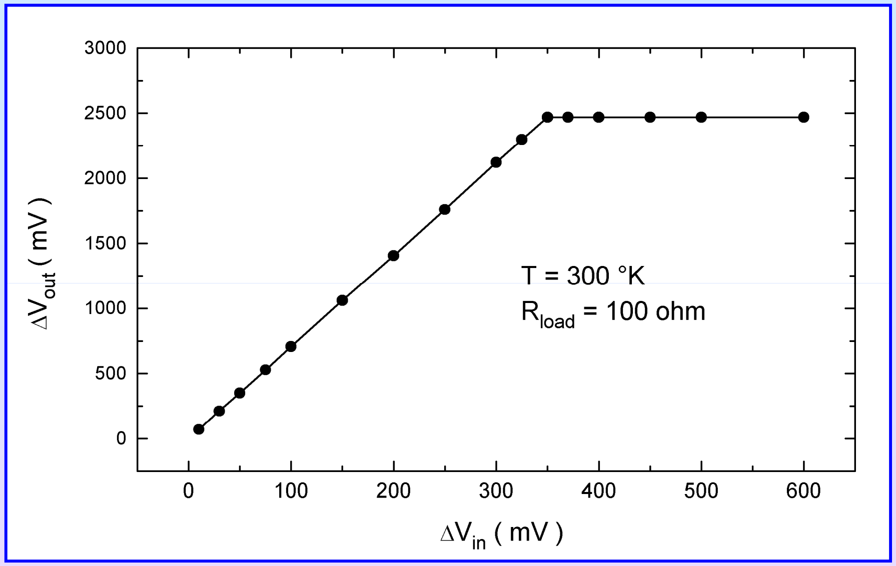
First test-bench characterization

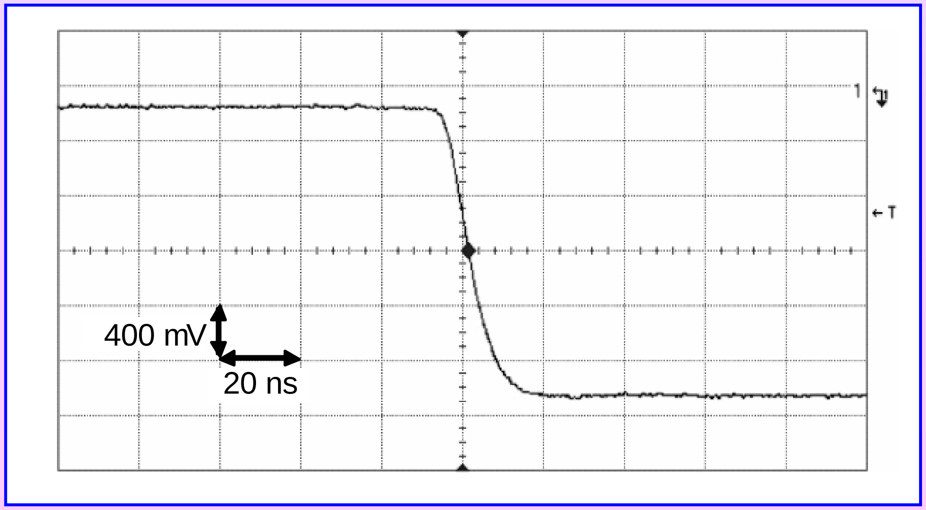
Negative output voltage swing of -2.5V against a negative power supply of -2.7V

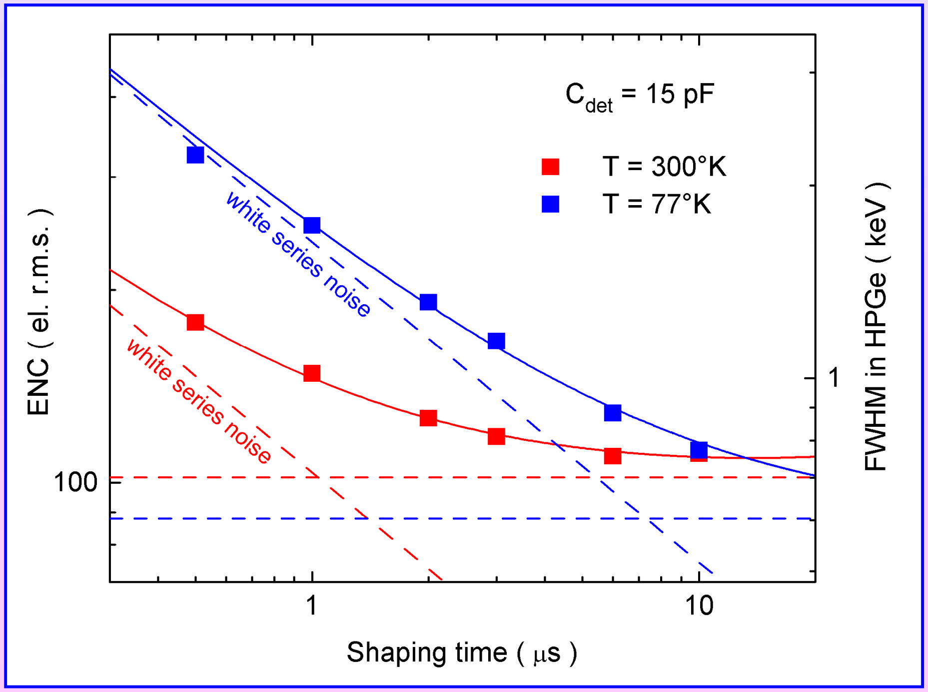
C_F = 0.2pF   dynamic energy range = ~ 8.6 MeV
(C_F= 1 pF dynamic energy range = ~ 45 MeV)

Rise time of ~ 13 ns (1m 50Ω terminated cable)
Rise time of ~ 15 ns (10m 50Ω terminated cable)

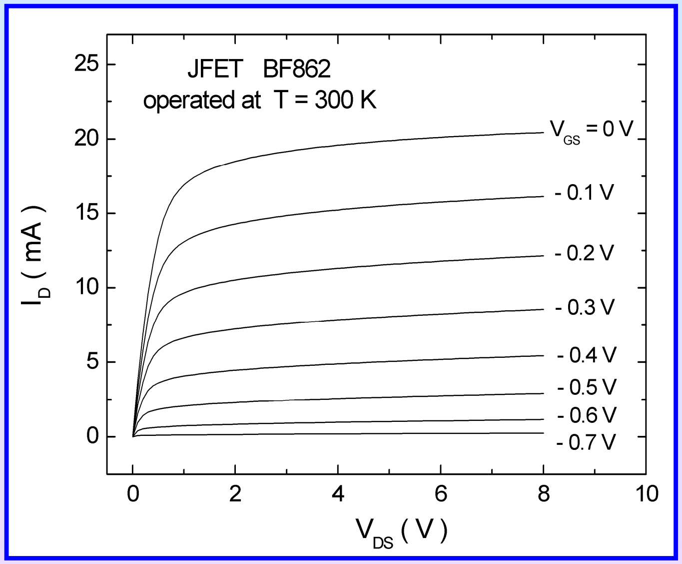
$C_{detector}$ = 15 pF
Minimum ENC ~ 110 e^- rms (0.76 keV fwhm in HPGe) both at 300K and 77K

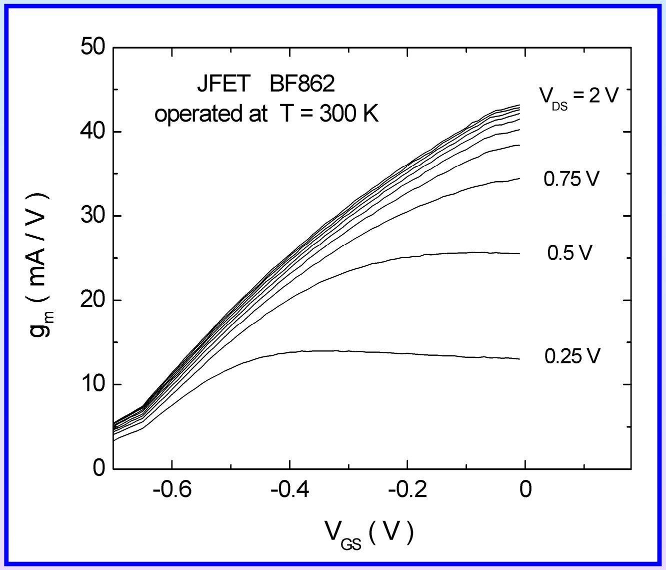






The BF862 JFET at T=300K and T=77K

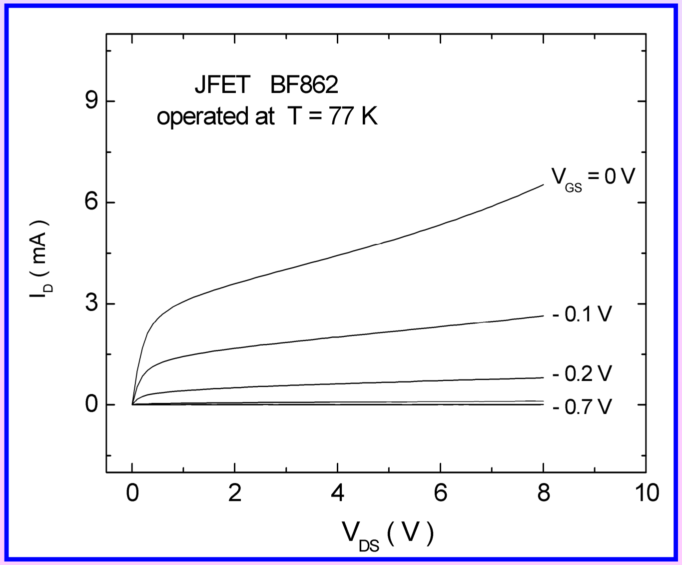


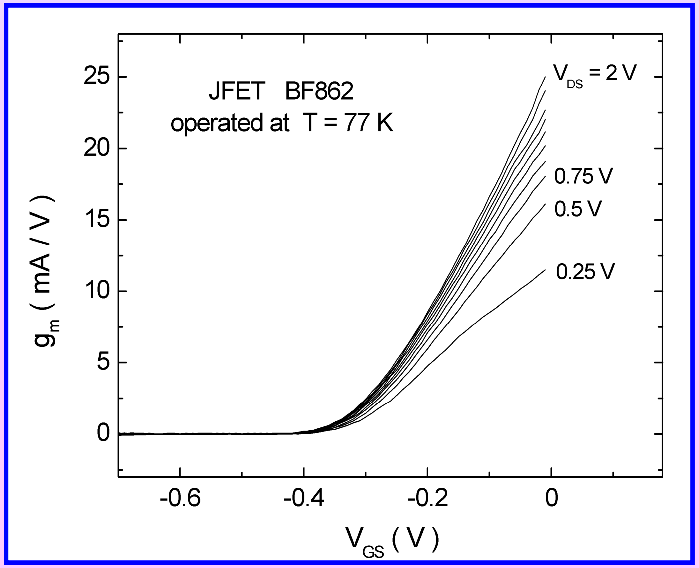


T= 300 K

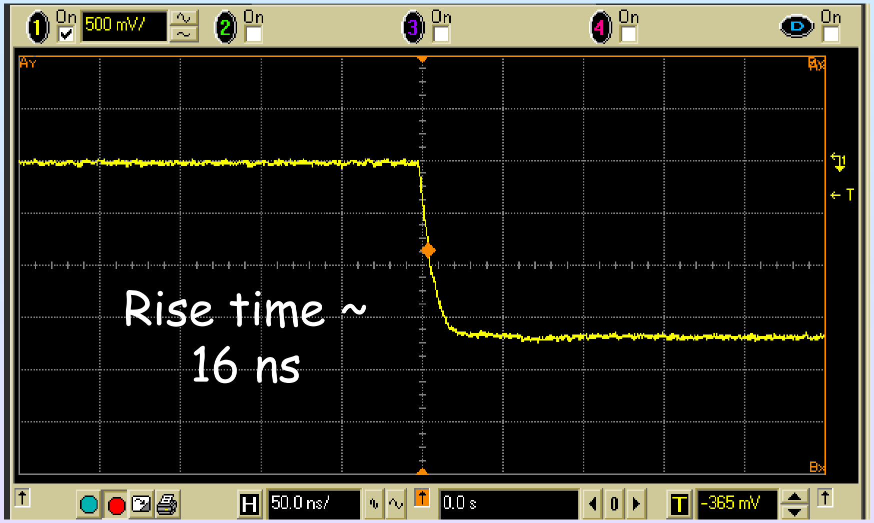
From 300K to 77K the drain current and so the transconductance value decrease of a factor of 3

T= 77 K

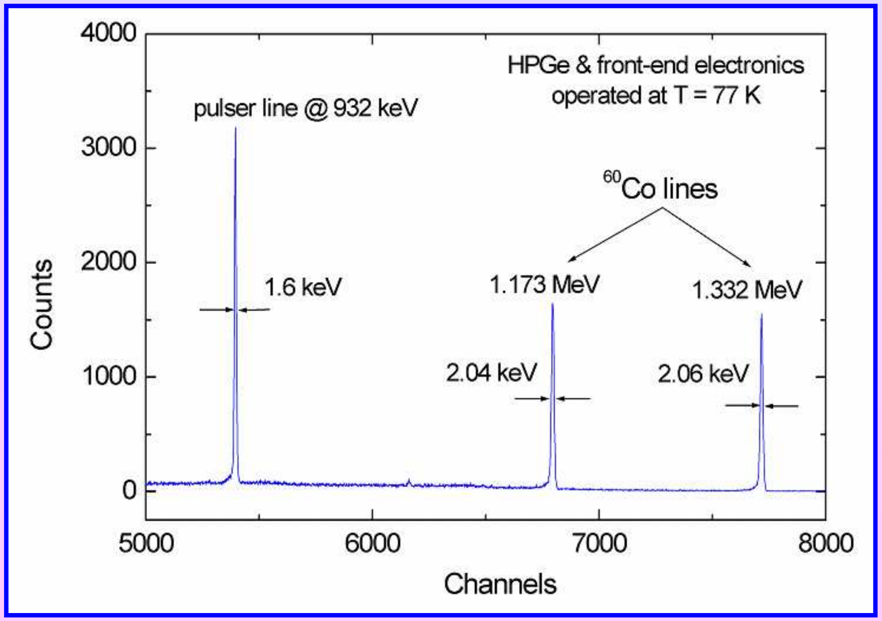




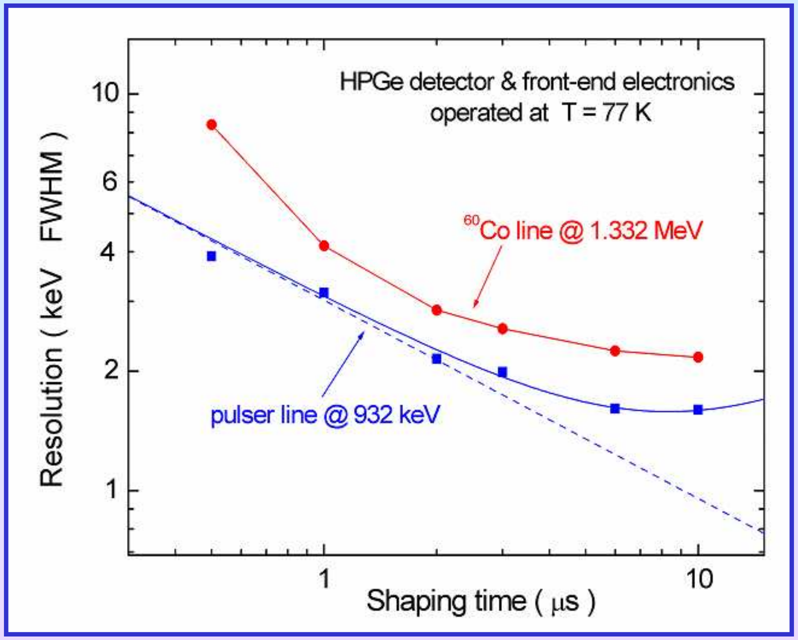
Measurement results with HPGe detector



Rise time ~
16 ns



Measurement made in Milano, April 2008, with detector setup "SUB" of GERDA experiment



C_{det} ~ 60 pF

Shaping time	Pulser line resolution (keV fwhm)	^{60}Co line resolution (keV fwhm)
0.5 µs	3.90	8.37
1 µs	3.16	4.14
2 µs	2.15	2.85
3 µs	1.99	2.56
6 µs	1.61	2.25
10 µs	1.60	2.17

Summarized preamplifier performance

	T = 77 °K
Energy sensitivity (C_F = 0.2 pF)	~ 290 mV/MeV at preamp output ~ 217 mV/MeV after 150Ω termination
Negative output voltage swing	~ 2.5 V
Input dynamic range	~ 8.6 MeV
Rise time	~ 16 ns with ~ 5m coaxial cable
Fall time	~ 250 µs (R_F = 1.2 GΩ)
Resolution	2.2 keV @ 1.332 MeV (^{60}Co) 1.6 keV on pulser line
Power required	23.4 mW (V_{FET} = +4V I_D = 2mA V_{CC}= +3.6V V_{EE} = -2.8V)

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low value of the feedback capacitance, for **maximization of the signal-to-noise ratio** (even if at the expense of the dynamic range)

very low power consumption:

JFET bias point:

V_D= 2.32 V I_D= 2.1 mA

P_{JFET} = 8.3 mW

P_{ASIC} = 15.1 mW

Conclusions

- A **TOT technique** has been adopted for AGATA preamplifiers and demonstrated with an AGATA capsule and a ^{241}Am+Be source. The obtained resolution in "**reset mode**" is of **< 0.4 %** in all the tested range on pulser signals **from 3 MeV to 50 MeV**. A remarkable resolution of **0.21 %** was obtained on the Ni spectrum line at the energy of **8.998 MeV.**

↓

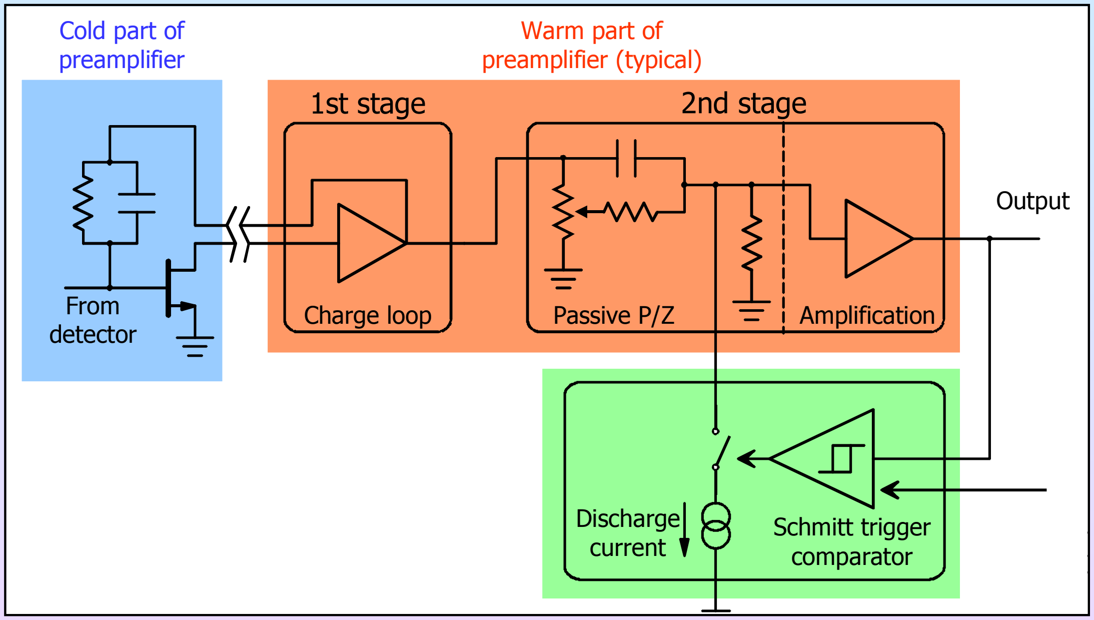
The energy measurement range can be extended of more than one order of magnitude

- A **JFET-CMOS preamplifier**, able to operate at cryogenic temperatures, has been realized and tested with a HPGe detector. The output stage provides at the same time a low output impedance and a large voltage swing.

↓

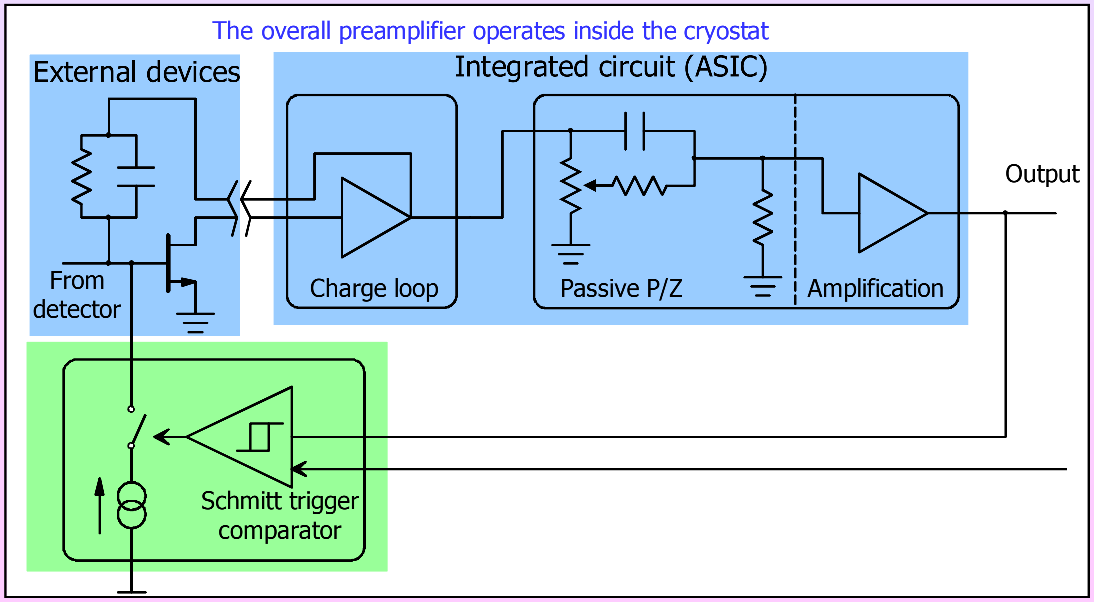
Future development: integration of the fast reset device in CMOS technology

De-saturation of 1st or 2nd stage ?



2nd stage de-saturation: HYBRID solution (AGATA)

- Cold part and warm hybrid part
- No added feed-through for reset
- No long-wire at the input node
- Need for a large output voltage swing of the first stage (± 12V power supplies)



1st stage de-saturation: INTEGRATED solution

- The overall circuit can operate inside the cryostat
- No added feed-through for reset
- Short wire at the input node
- Higher power dissipation inside the cryostat (risk of micro boiling?)