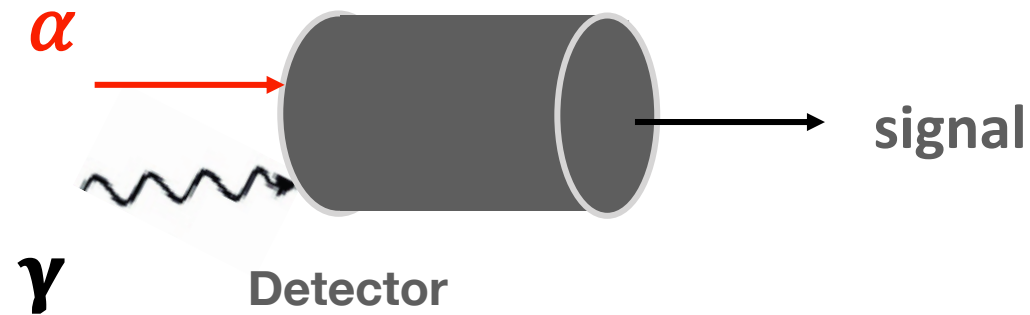


# Lecture: Pulse signal processing

**Chapters 11.1, 11.2, 11.3,  
12.1, 12.2,  
14.1, 14.2, 14.3.1, 14.3.2, 14.9, 14.10,  
14.11, 14.12,  
15.1, 15.2, 15.3**

Detector output signal:

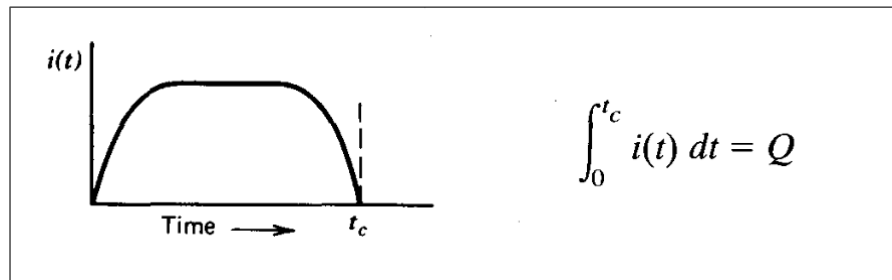
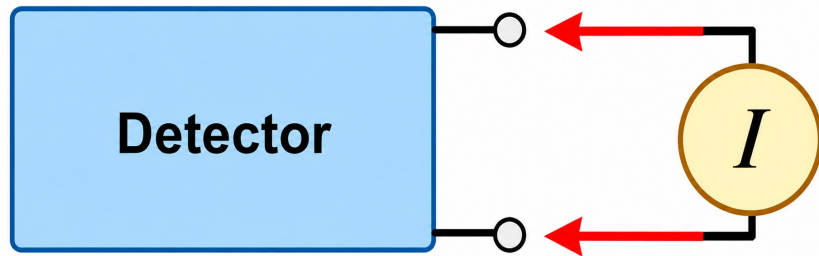
1. Current mode
2. Pulse mode (Voltage mode)



In radiation spectroscopy we want to preserve the information of the incoming radiation (such as energy, time).

Pulse mode does this

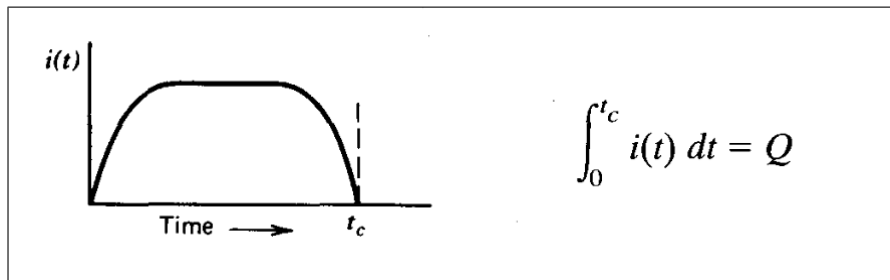
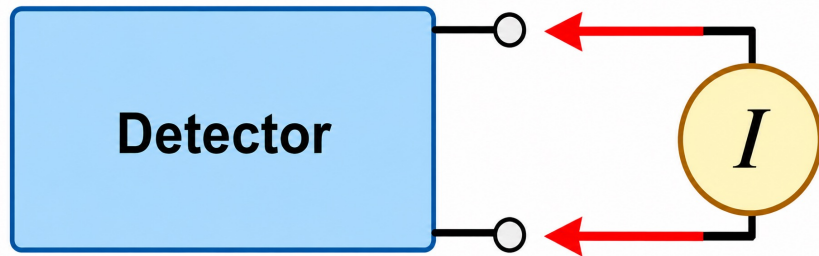
Before moving on the pulse mode  
little overview of current mode



○ The sketch illustrates the response of a detector to a single radiation interaction.

○ The time dependence of the detector current is shown on the left, where  $t_c$  represents the charge collection time.

○ The total charge  $Q$  generated in the interaction is given by the area under the current pulse:

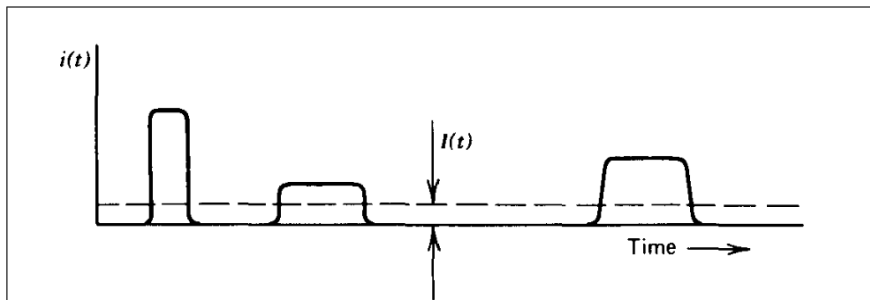


○ The sketch illustrates the response of a detector to a single radiation interaction.

○ The time dependence of the detector current is shown on the left, where  $t_c$  represents the charge collection time.

○ The total charge  $Q$  generated in the interaction is given by the area under the current pulse:

## Current mode:



○ Measures the average current from many events

○ A long response time averages over individual pulses,  $I_0$ :

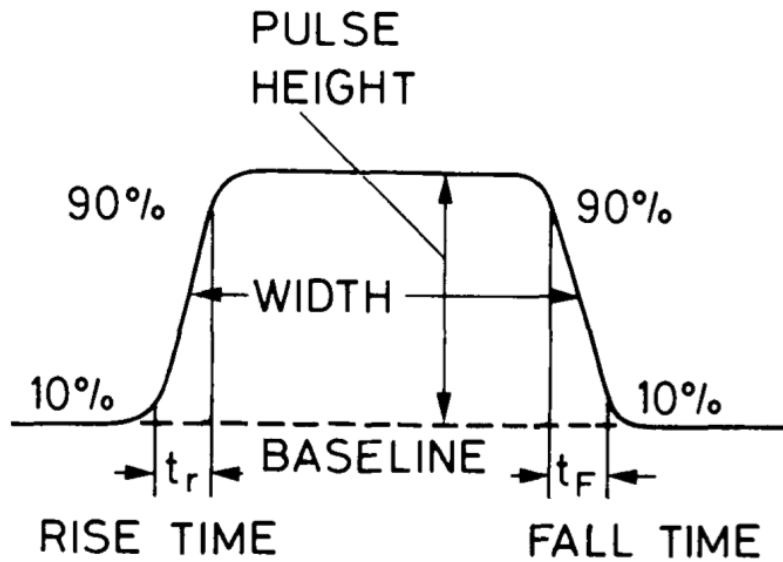
$I_0 = rQ$  ( $r$ : event rate,  $Q$ : Charge produced for each event)

○ Useful at very high event rates

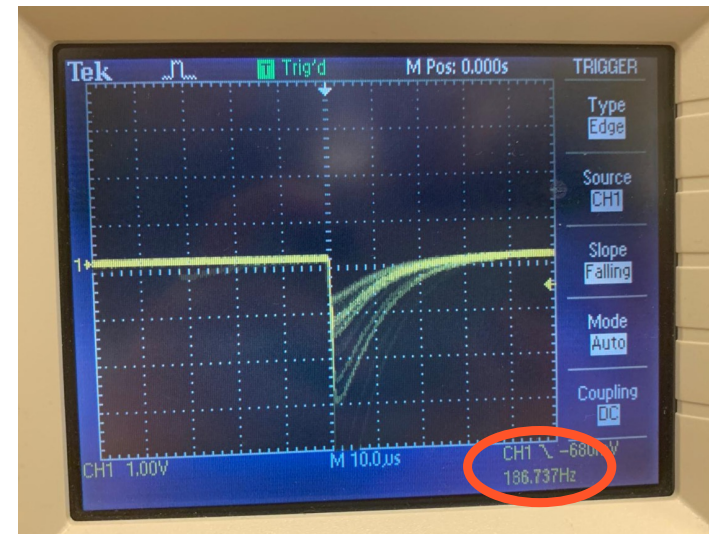
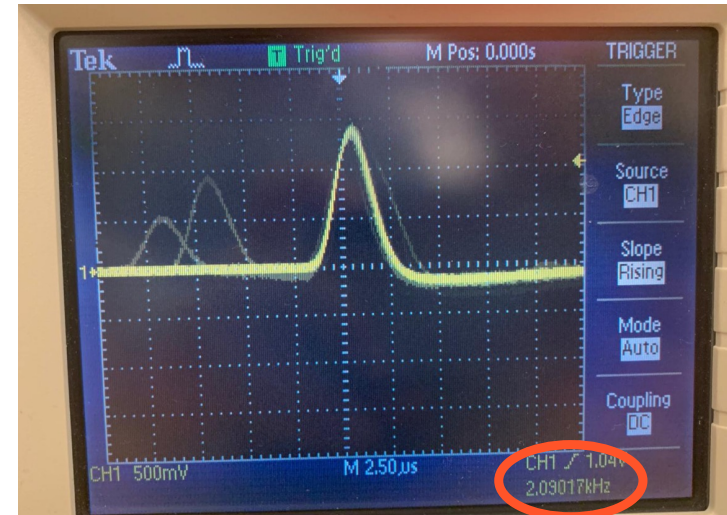
○ Individual pulse heights are not preserved

# pulse signal in pulse mode

Voltage, V  
Time, sec



4



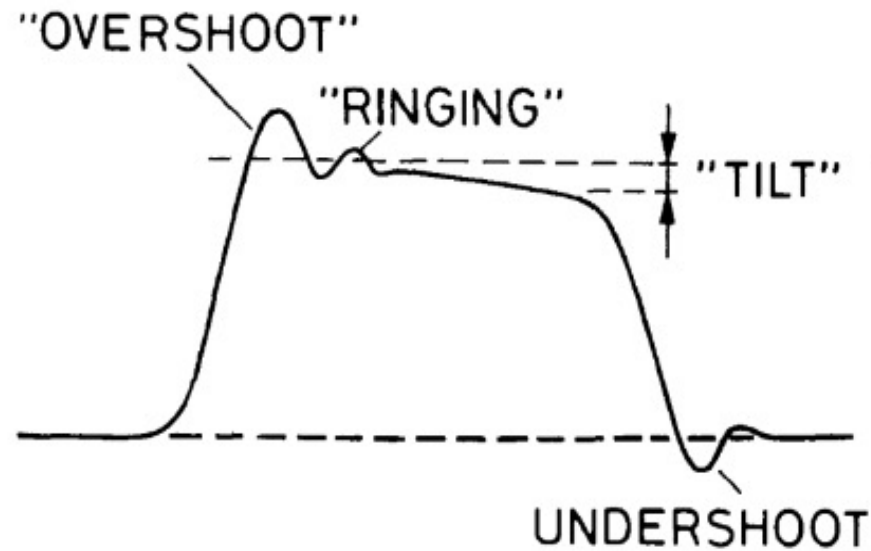
Detection rate

# Detection rate of a given radiation

$$Frequency = \frac{Oscillations}{time}$$

$$Frequency = \frac{Counts}{time} = \frac{Counts}{sec} = Hz$$

$$1kHz = 1000 \text{ counts/sec}$$



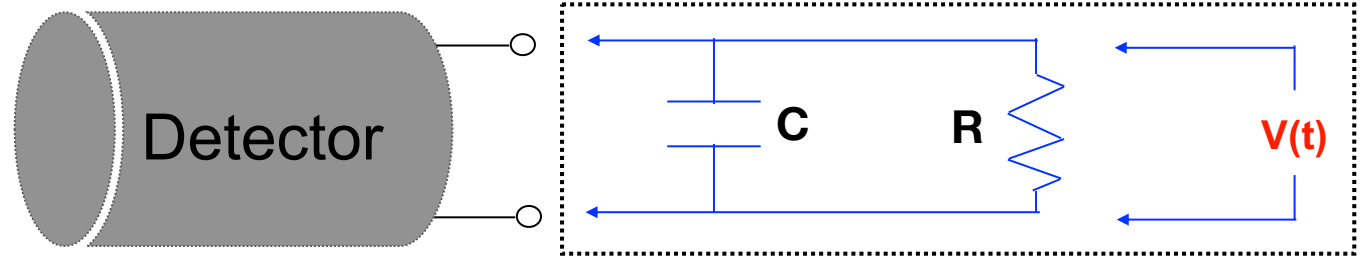
### Causes

- Impedance mismatches
- long cables
- parasitic capacitance

### Solutions

- Shorten cables: reduce parasitic capacitance
- Add damping resistance: suppress ringing/overshoot
- Adjust load resistance : control  $RC$  time constant
- Low-pass filtering: suppress high-frequency fluctuations

## Pulse mode: Voltage pulse



R: Input resistance of the circuit

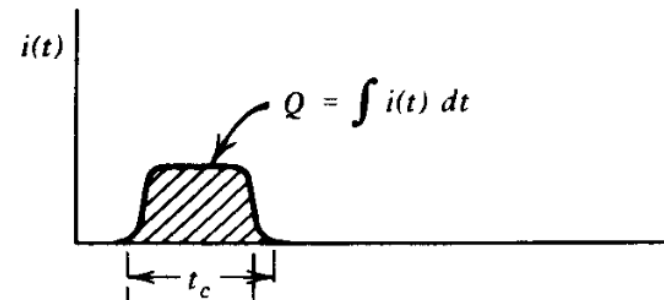
C: Equivalence capacitance

$C = C_{\text{det.}} + C_{\text{preamplifier}} + C_{\text{cable}}$

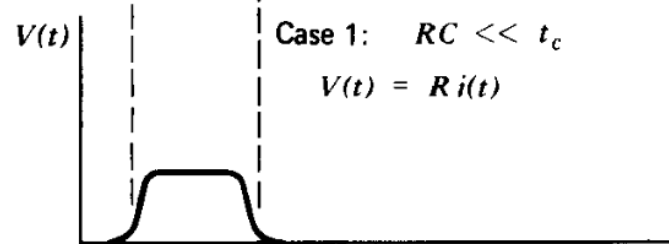
Pulse mode is obtained via connecting the detector to an external circuit with R and C in series.

**RC circuits are timing circuits where RC is the time constant.**

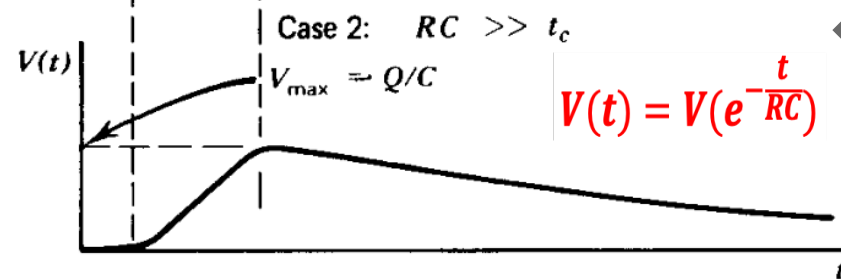
$$RC = \frac{VQ}{IV} = \frac{\text{Volt}}{\text{Amper}} \frac{\text{Coulomb}}{\text{Volt}} = \frac{\text{Coulomb}}{\text{Amper}} = \frac{\text{Coulomb}}{\text{Coulomb/sec}} = \text{sec}$$



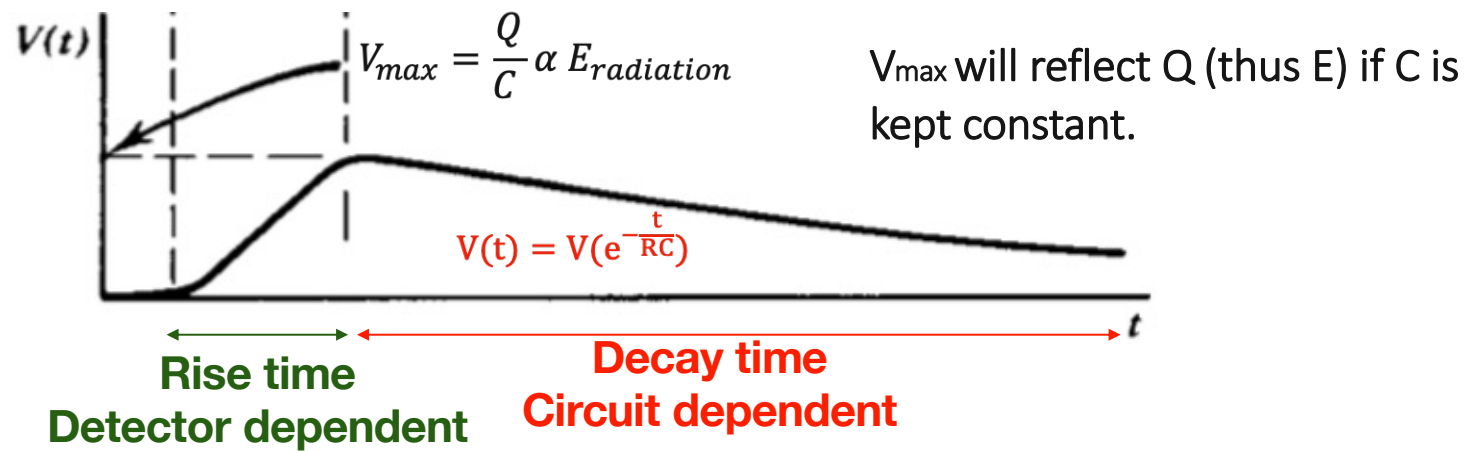
$t_c$ : charge collection time  
(ns-ms)



← The circuit is much faster than the detector.



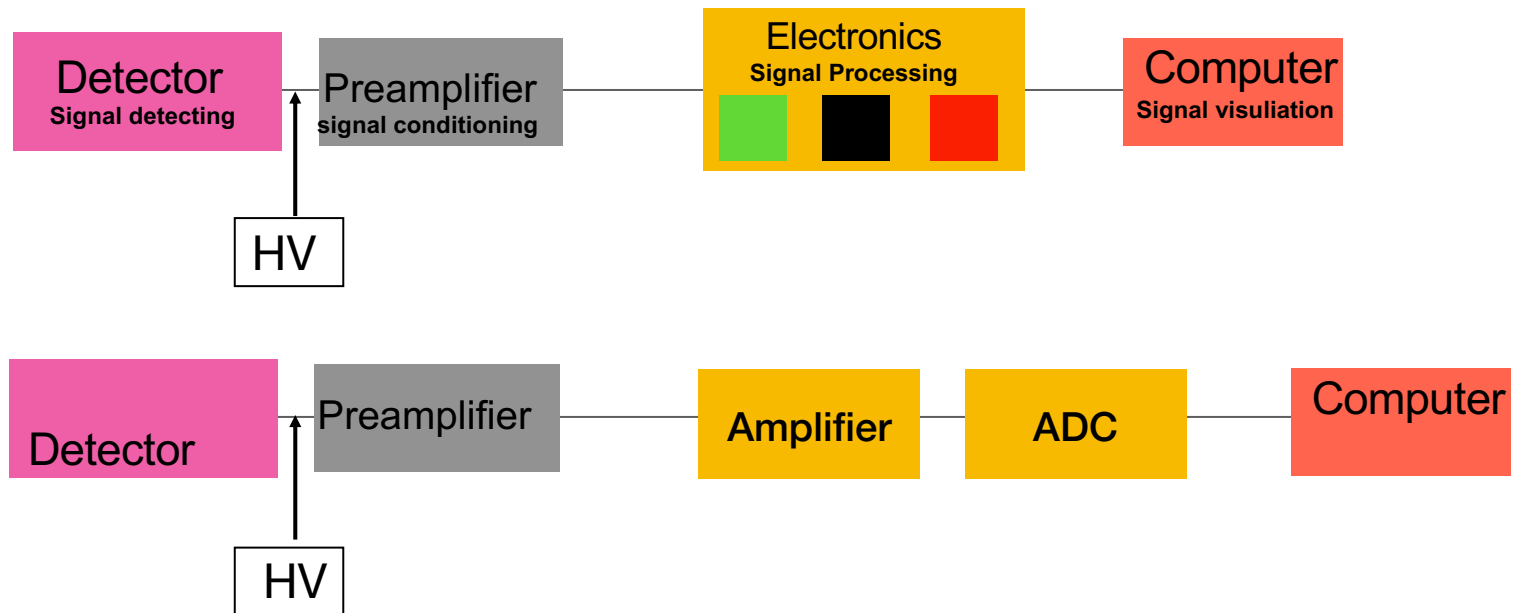
← The circuit is much slower than the detector.



Ionisation chambers  
 $t_c$ =few milliseconds

Semiconductor detectors  
 $t_c$ =few nanoseconds

# Simple counting system



# Today

- HV power supply
- Preamplifier (PA)
- Linear Amplifier (LA)
- MCA (Multi-Channel Analyzer)
  - ADC (Analog-to-Digital Converter)
  - Memory
- NIM and CAMAC standards (Modular electronics)

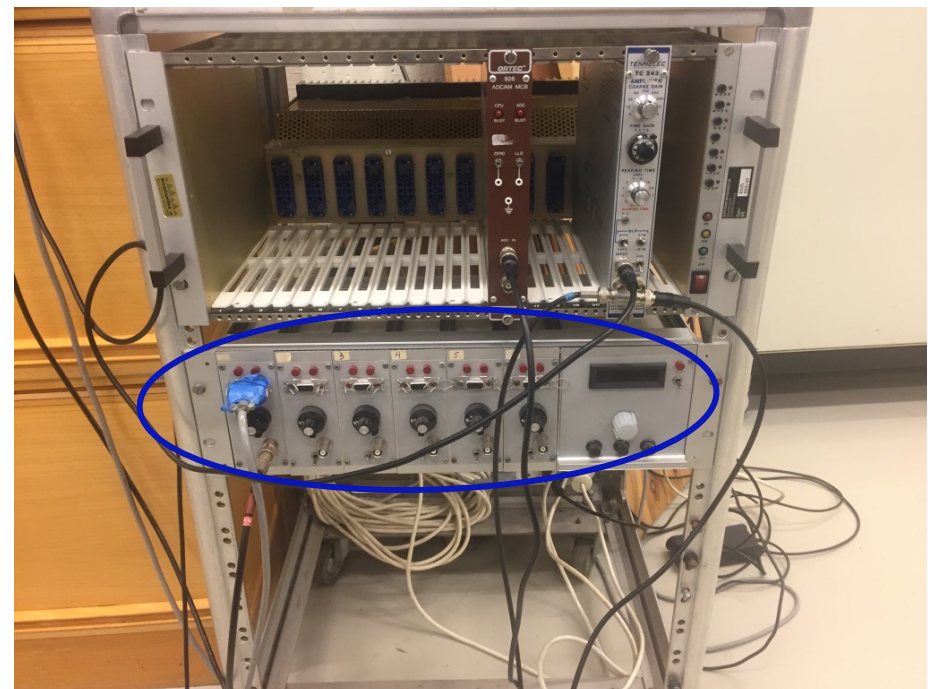
# High-Voltage Power Supply

The HVPS provides a positive or negative voltage necessary for the operation of the detector.

Most detectors need positive high voltage. Typical values are given in the table.

**TABLE 1.2**  
**High Voltage Needed for Certain Common Detectors**

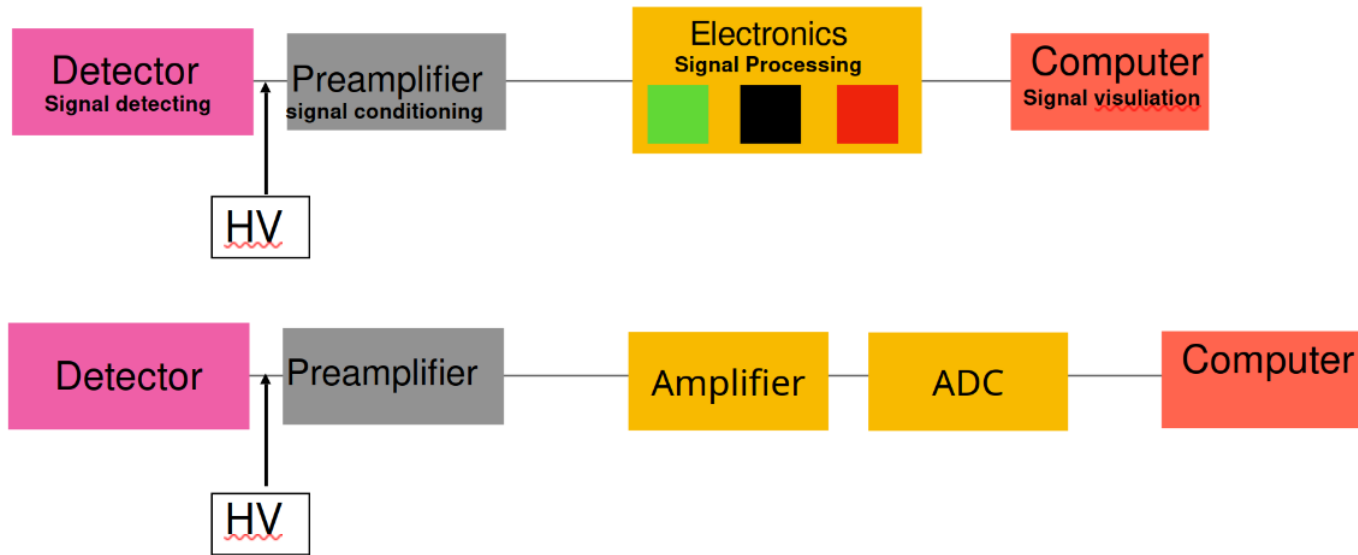
| Detector                       | High Voltage (V) |
|--------------------------------|------------------|
| Ionization counters            | HV < 1000        |
| Proportional counters          | 500 < HV < 1500  |
| GM counters                    | 500 < HV < 1500  |
| Scintillators                  | 750 < HV < 1250  |
| Neutron detectors              | 1000 < HV < 2000 |
| <b>Semiconductor Detectors</b> |                  |
| Surface-barrier                | HV < 100         |
| Hyper-pure germanium           | 2500 < HV < 4500 |



# Preamplifier



- Primary purpose of PA is to provide an optimized coupling between the output of the detector and the rest of the counting system.
- Extracts the signal from the detector without significantly degrading the intrinsic signal-to-noise (S/N) ratio, by minimizing possible sources of noise.
- Deliver to the next unit (=Shaping or Linear) Amplifier
- Has to be very close to the detector with a small output signal!
- A PA couples the detector signal to the subsequent electronics while preserving S/N. Depending on the detector and application, it may provide impedance matching, signal amplification, charge integration, or a combination of these.



## 1-current sensitive

Requires low-impedance devices (small  $Z_I$ )

Not suitable for radiation detection where  $Z_I$  is high.

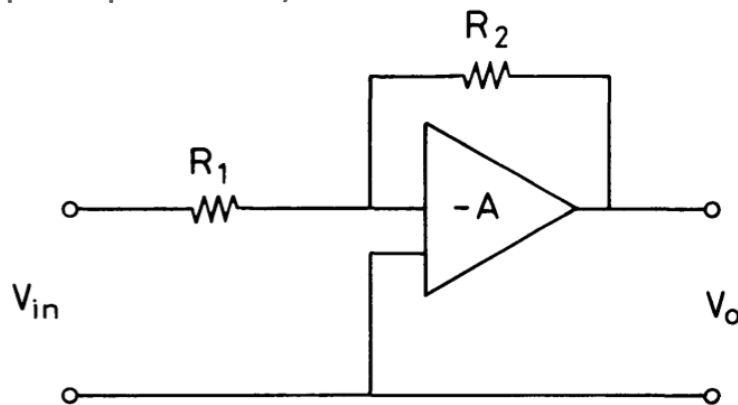
Details in Leo Page#278-279  
Knoll: 610-13

## 2- voltage sensitive

- The voltage appears through the intrinsic capacitance of the detector plus any other stray capacitances which may be in the input circuit
- $V_{out}$  has strong dependence on  $C_{det.}$  and therefore  $C_{det.}$  should be stable and not changing with temperature.
- Semiconductor detectors are very sensitive to temperature changes and thus their capacitance. So we don't use these PAs for semiconductor detectors.
- **They are suitable for PMT (i.e. scintillation detectors), Proportional and Geiger-Muller counters.**

**$R_2$ : feedback resistance**

A: (Operational) Amplifier  
(op-amp circuits)



Assume  $A \gg R_2/R_1$

$$V_{out} \cong -\frac{R_2}{R_1} V_{in}$$

↓

$$V_{in} = \frac{Q}{C_{tot}}$$

Where

$$C_{tot} = C_{det} + C_{circuit} + C_{cable}$$

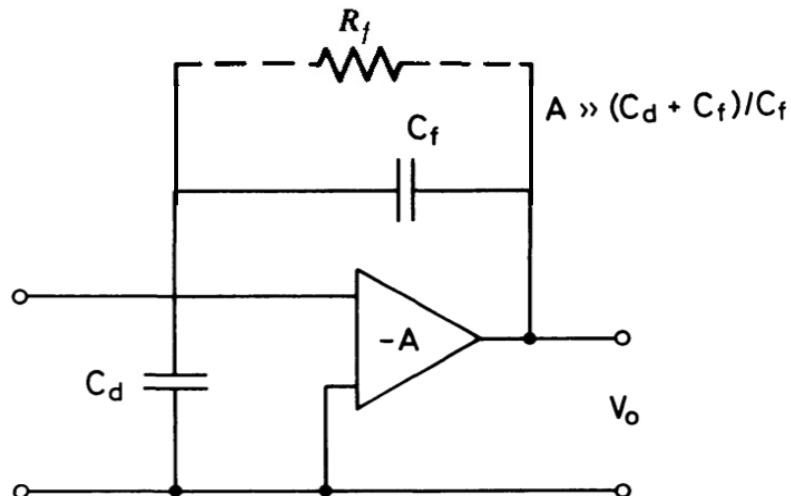
Details in Leo Page#278-279  
Knoll: 610-13

### 3- charge-sensitive

- The charge-sensitive PA integrates the charge carried by the incoming pulse on the feedback capacitor  $C_f$ .
- Thus, the output voltage is always proportional to  $-Q/C_f$  and *not to the capacitance of the detector*.
- Suitable for semiconductor detectors like Si and Ge.

$R_f$ : feedback resistance

A: (Operational) Amplifier



$$V_o = -AV_{in} = -A \frac{Q}{C_d + (A+1)C_f} \simeq -\frac{Q}{C_f}$$

## Detector Signals and the Role of the Preamplifier

| Detector                     | Physical charge multiplication?                | Signal at the preamplifier               | Typical preamplifier                    | Main job of the preamplifier                                                          |
|------------------------------|------------------------------------------------|------------------------------------------|-----------------------------------------|---------------------------------------------------------------------------------------|
| <b>Ionization chamber</b>    | No                                             | Very small charge / current              | Current- or charge-sensitive            | Very-low-noise current/charge measurement and conversion to voltage                   |
| <b>Ge / Si semiconductor</b> | No                                             | Small charge $Q$                         | Charge-sensitive                        | Convert $Q$ to voltage, $V_{out} \approx -Q/C_f$ , with minimum added noise           |
| <b>Proportional counter</b>  | Yes — gas avalanche                            | Amplified charge                         | Charge-sensitive                        | Convert amplified charge to voltage; preserve energy information; buffer signal       |
| <b>Drift chamber</b>         | Yes — gas avalanche                            | Amplified, fast charge / current pulse   | Fast current- or charge-sensitive       | Amplify and condition the fast signal; preserve timing information                    |
| <b>PPAC</b>                  | Yes — gas avalanche                            | Amplified, very fast pulse               | Fast current- / charge-sensitive        | Fast signal amplification and conditioning; timing and position information           |
| <b>TPC</b>                   | Usually yes — gas amplification at the readout | Amplified charge pulses on many channels | Low-noise charge-sensitive              | Convert charge to voltage; shape/amplify; preserve charge and timing information      |
| <b>Geiger-Müller counter</b> | Yes — very large Geiger avalanche              | Large pulse                              | Often no PA required                    | If used: buffering, impedance matching and pulse conditioning; little additional gain |
| <b>Scintillator + PMT</b>    | Yes — PMT electron multiplication              | Relatively large charge / current pulse  | Current-, voltage-, or charge-sensitive | Buffering, impedance matching, charge/voltage conversion; additional gain if needed   |

## Output of a PA: pile up is encountered

Pulse from Preamplifier

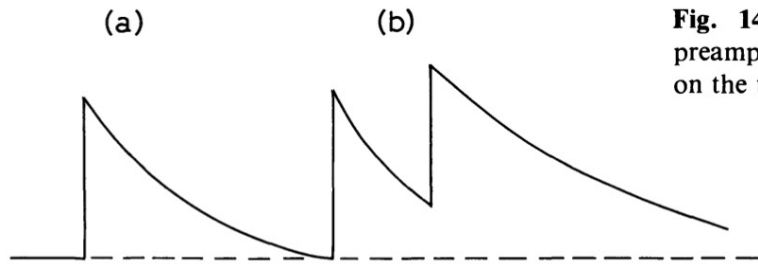
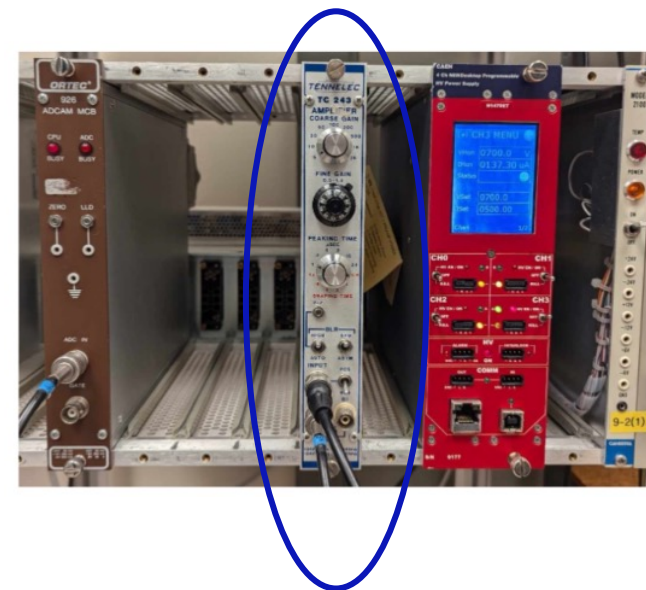


**Fig. 14.3.** (a) Exponential *tail* pulse from a preamplifier, (b) *pulse pileup*: a second pulse rides on the tail of the first

Discharge over feedback resistance produce long exponential tail (40-50  $\mu\text{s}$  or longer).

- We can either reduce the counting rate to less than  $1/\tau$  counts/sec
- OR shorten the tail by reshaping. We need linear amplifier!!

# Linear Amplifier (Shaping Amplifier)



- An amplifier magnifies the amplitude of the preamplifier output pulse from the mV range into the 0.1- to 10-V range.
- This facilitates accurate pulse amplitude measurements with analog-to-digital converters
- The amplifier shapes the pulses to optimize the energy resolution, and to minimize the risk of overlap between successive pulses by shortening the time duration of the signal.
- Most amplifiers also incorporate a baseline restorer to ensure that the baseline between pulses is held rigidly at ground potential in spite of changes in counting rate or temperature.

## 1- CR-RC Pulse Shaping

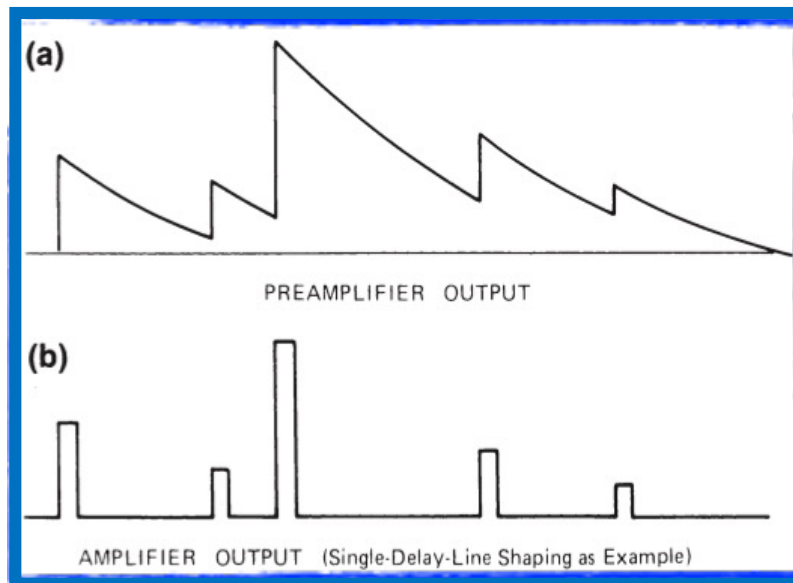
## 2-Double Differentiation or CR-RC-CR Shaping

## 3-Semi-Gaussian Shaping

## 4-Delay-Line Pulse Shaping (Scint. detectors)

Output signal is in squared form

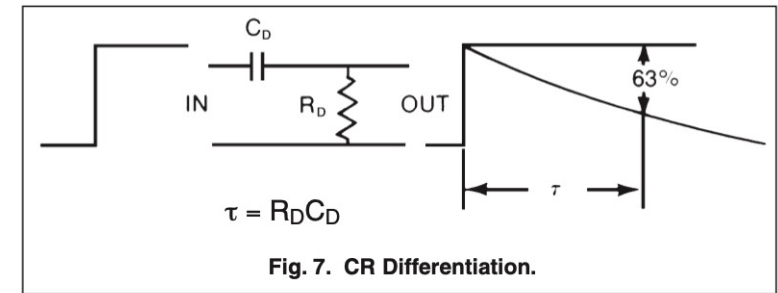
Signal-to-noise ratio is poorer compared to CR-RC shaping



## 1- CR-RC Pulse Shaping

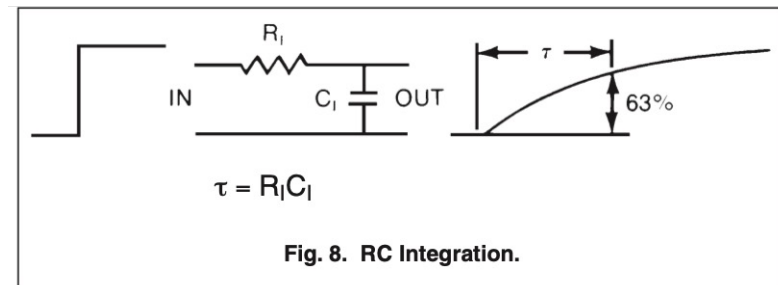
### 1. CR differentiator — high-pass filter

- Removes low-frequency noise
- Shortens the long decay tail of the preamplifier pulse



### 2. RC integrator — low-pass filter

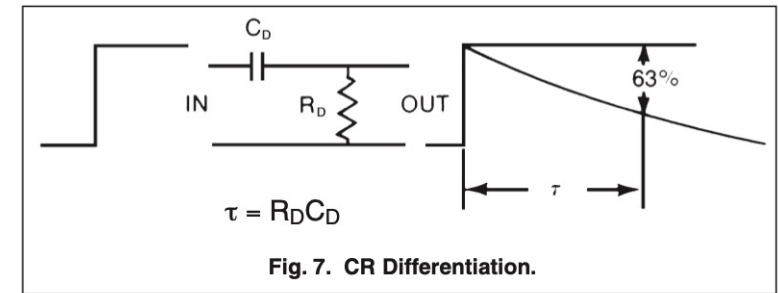
- Removes high-frequency noise
- Smooths the pulse
- Lengthens the rise time



## 1- CR-RC Pulse Shaping

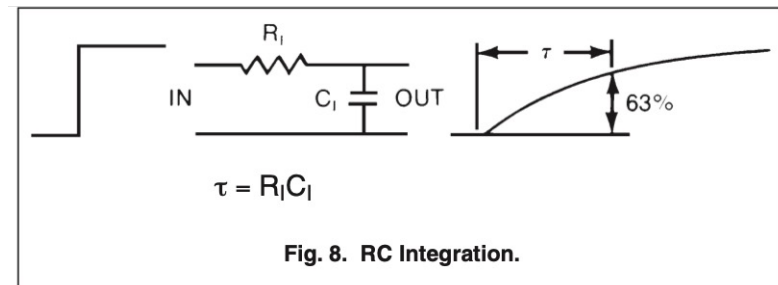
### 1. CR differentiator — high-pass filter

- Removes low-frequency noise
- Shortens the long decay tail of the preamplifier pulse

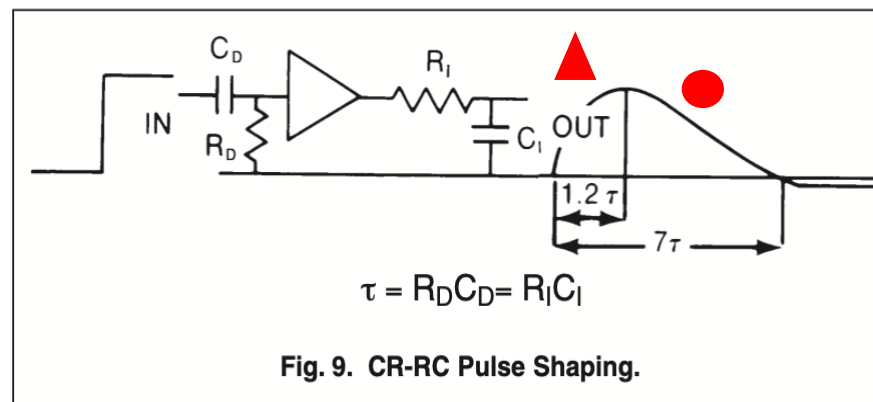


### 2. RC integrator — low-pass filter

- Removes high-frequency noise
- Smooths the pulse
- Lengthens the rise time



CR+RC → shorter, smoother pulse, approximately Gaussian



# Output of a LA: pile up can still be encountered!

Overshoot  
Undershoot pileups

Resulting energy  
histogram

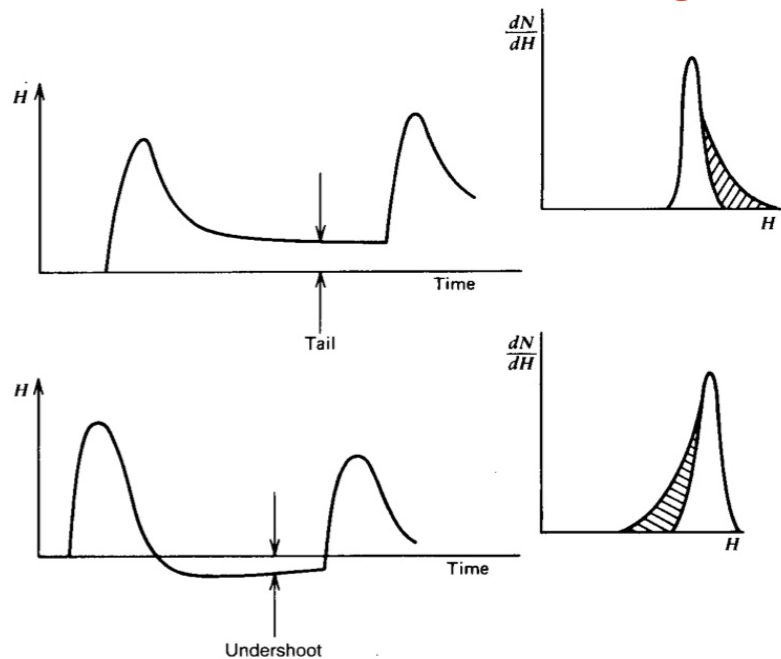


**Figure 17.17** Pile-up from the tail or undershoot of a preceding pulse. Both are usually categorized as tail pile-up. The effect on the differential pulse height spectrum for constant amplitude pulses is shown as the cross-hatched area at the right.

peak pile-up

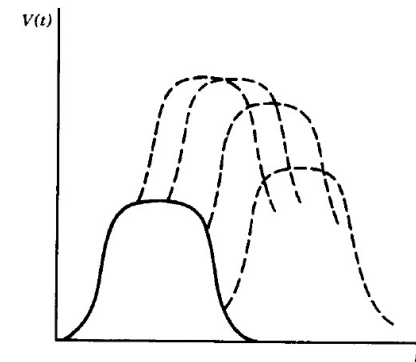


**Figure 17.18** Peak pile-up, in which two closely spaced signal pulses combine to form one distorted pulse. Several different cases are sketched with increasing overlap between the first and second pulse.

pole-zero cancellation or active baseline restoration techniques discussed in Chapter 16 in Knoll.

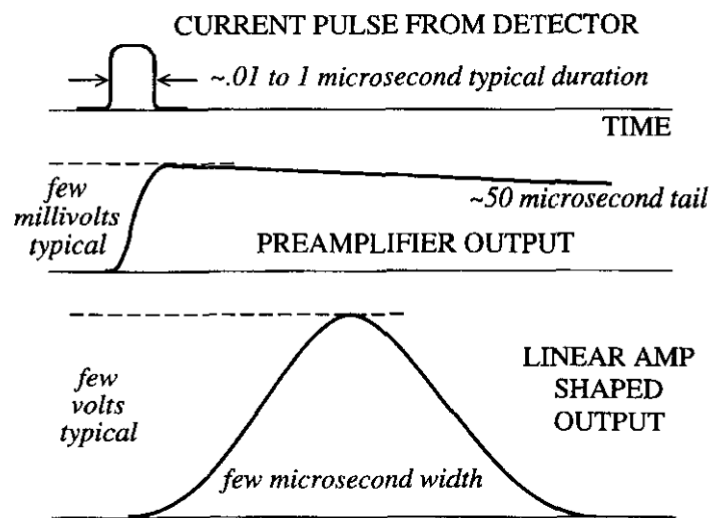
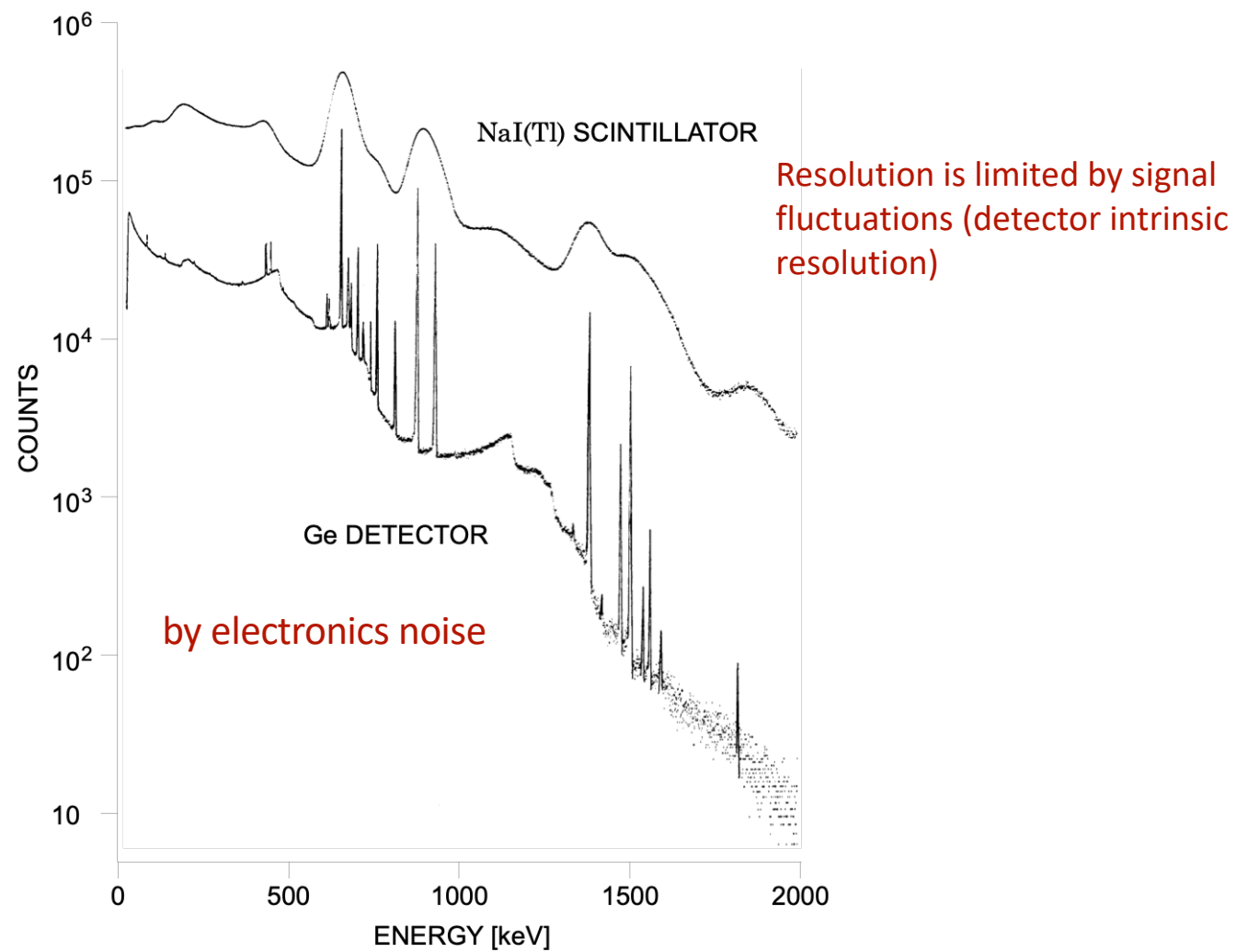


**Figure 17.8** Intercomparison of typical pulses at sequential points along the signal processing chain.



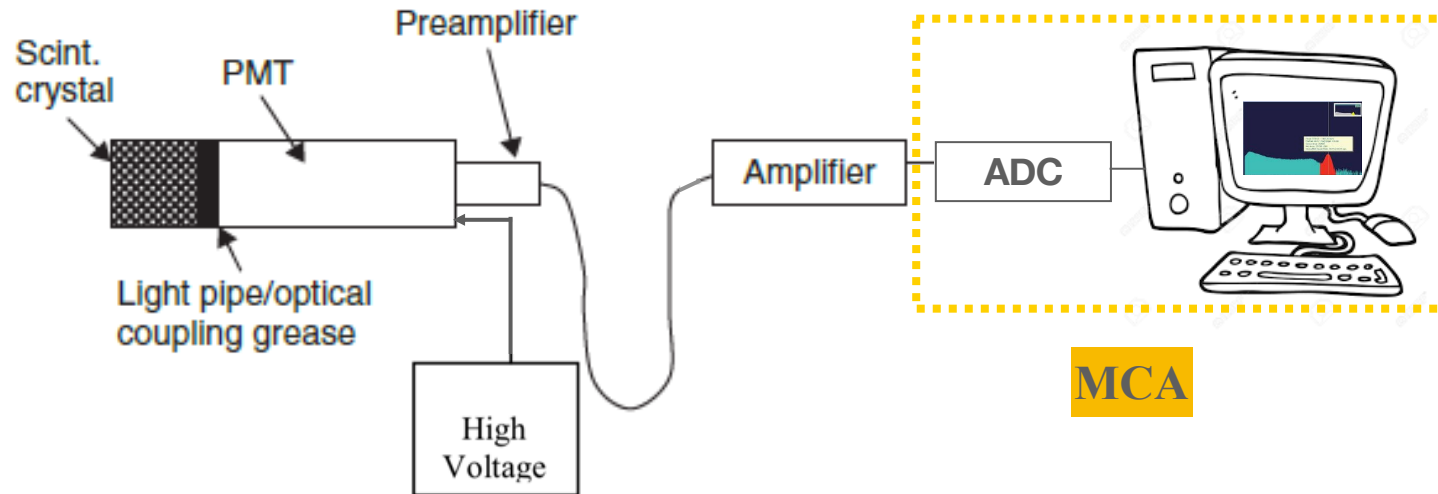
## Sources of fluctuations in the peak width, $\Delta E = \text{FWHM}$

- **Drift** of the operating characteristics of the detector during the experiment. (Magnetic field near the detector or room temperature change, light in the room, over irradiation)
- **Random noise** within the detector and in the electronics processing the detector output signal
- **Statistical noise**, discrete nature of the measured signal (intrinsic resolution)

$$(\text{FWHM})_{\text{overall}}^2 = (\text{FWHM})_{\text{statistical}}^2 + (\text{FWHM})_{\text{noise}}^2 + (\text{FWHM})_{\text{drift}}^2 + \dots$$

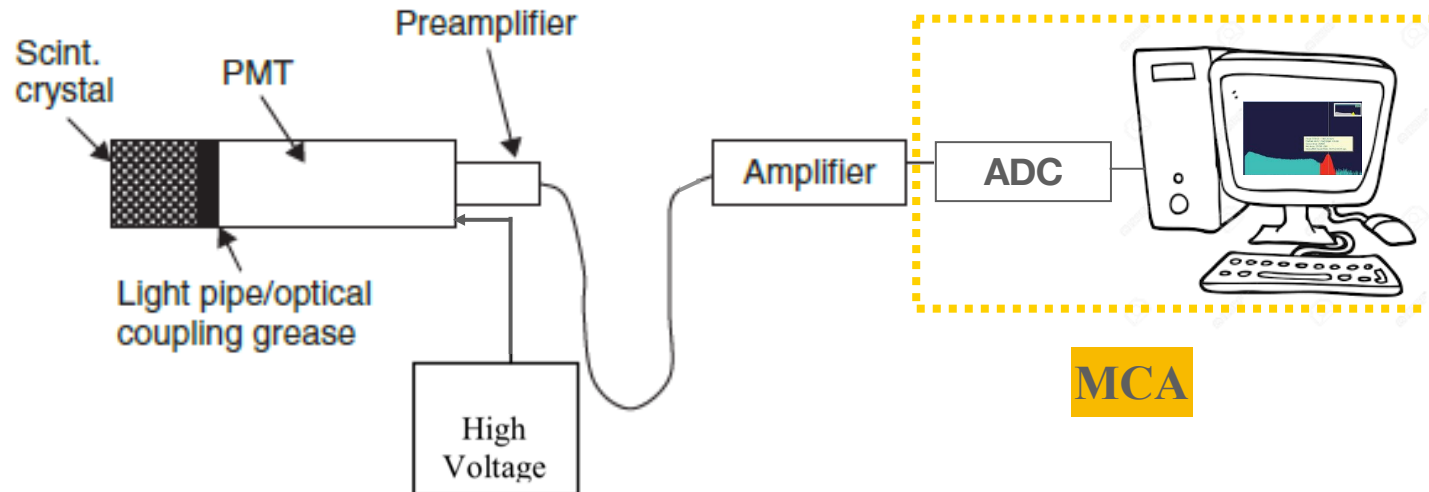
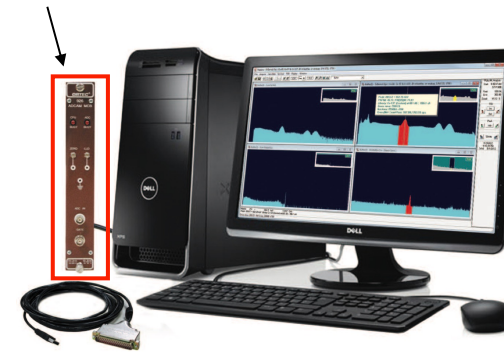
# Radiation Measurement system

for pulse-height or energy spectroscopy



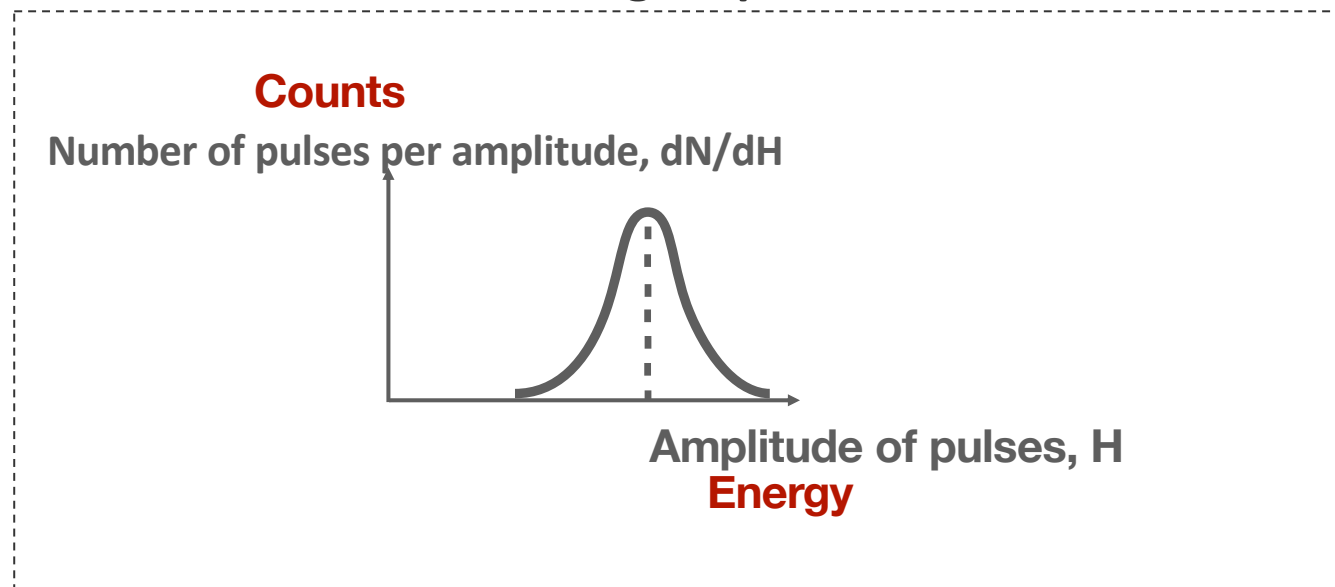
# Radiation Measurement system for pulse-height or energy spectroscopy

**ORTEC:  
926-M-USB  
Multichannel Analyzer (MCA)**



# MCA (Multi-Channel Analyzer)

## Pulse height spectrum



## MCA (Multi-Channel Analyzer)

ADC (Analog-to-Digital Converter)

Memory

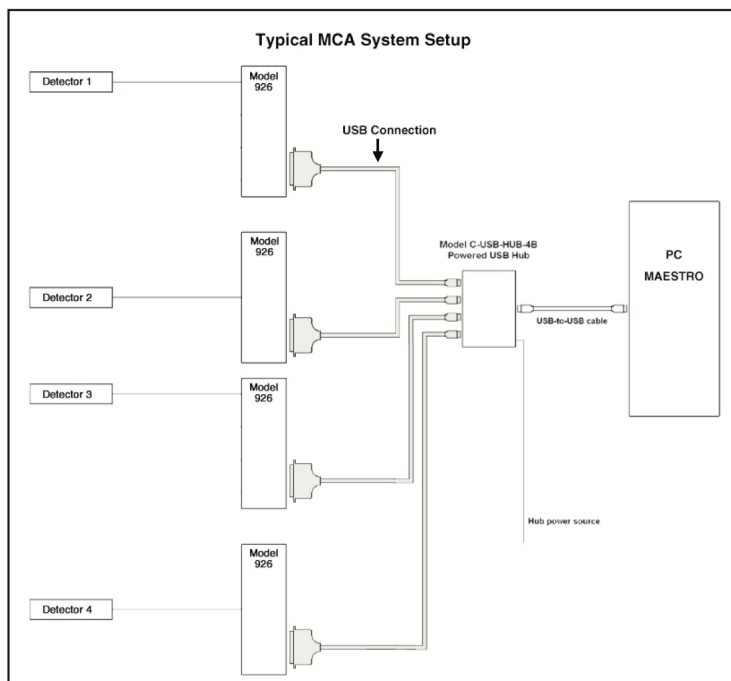
Display

*In old times*



## MCA (Multi-Channel Analyzer)

ADC (Analog-to-Digital Converter)  
Memory **MCB**  
PC + Maestro software



*At present*



**ORTEC:**  
**926-M-USB**  
**Multichannel**  
**Analyzer (MCA)**

# Analog-to-Digital Converter, ADC

## Memory

ADC: Analog-to-Digital Converter

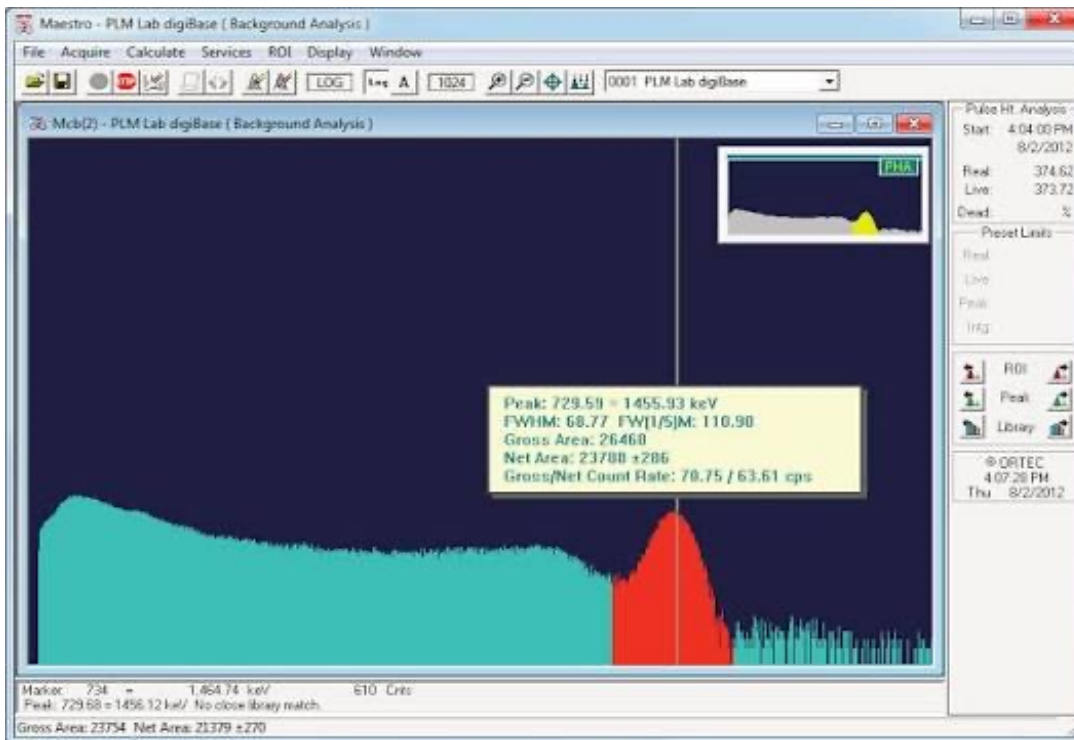
- The ADC does the critical job by converting amplitude of each pulse to a digital number
- Analog signal contains the information such as energy or time and is converted into an equivalent digital form.
- It is the fundamental link between analog and digital electronics.
- The conversion is based on dividing the pulse amplitude range into a finite number of discrete intervals, i.e. “channels” which generally range from 512 ( $2^9$ ) to 65536 ( $2^{16}$ )

Memory:

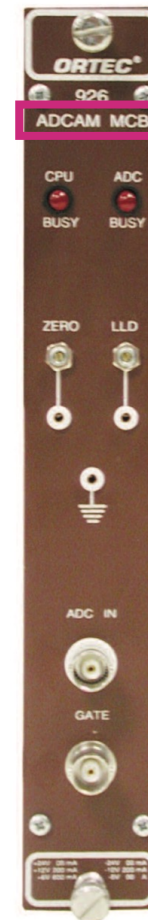
- The number of pulses corresponding to each channel is kept by taking the output of the ADC to a memory location

## 13 bit ADC

MAX RESOLUTION 8192 ( $2^{13}$ ) channels,  
software selectable as 8192, 4096, 2048,  
1024, and 512.



## ADC



ORTEC:  
926-M-USB  
Multichannel  
Analyzer (MCA)

## Memory



**DATA MEMORY** 8k channels of  
battery backed-up memory;  $2^{31}-1$   
counts per channel (over 2 billion).

## Example:

ADC accepts 0-10 V of signals

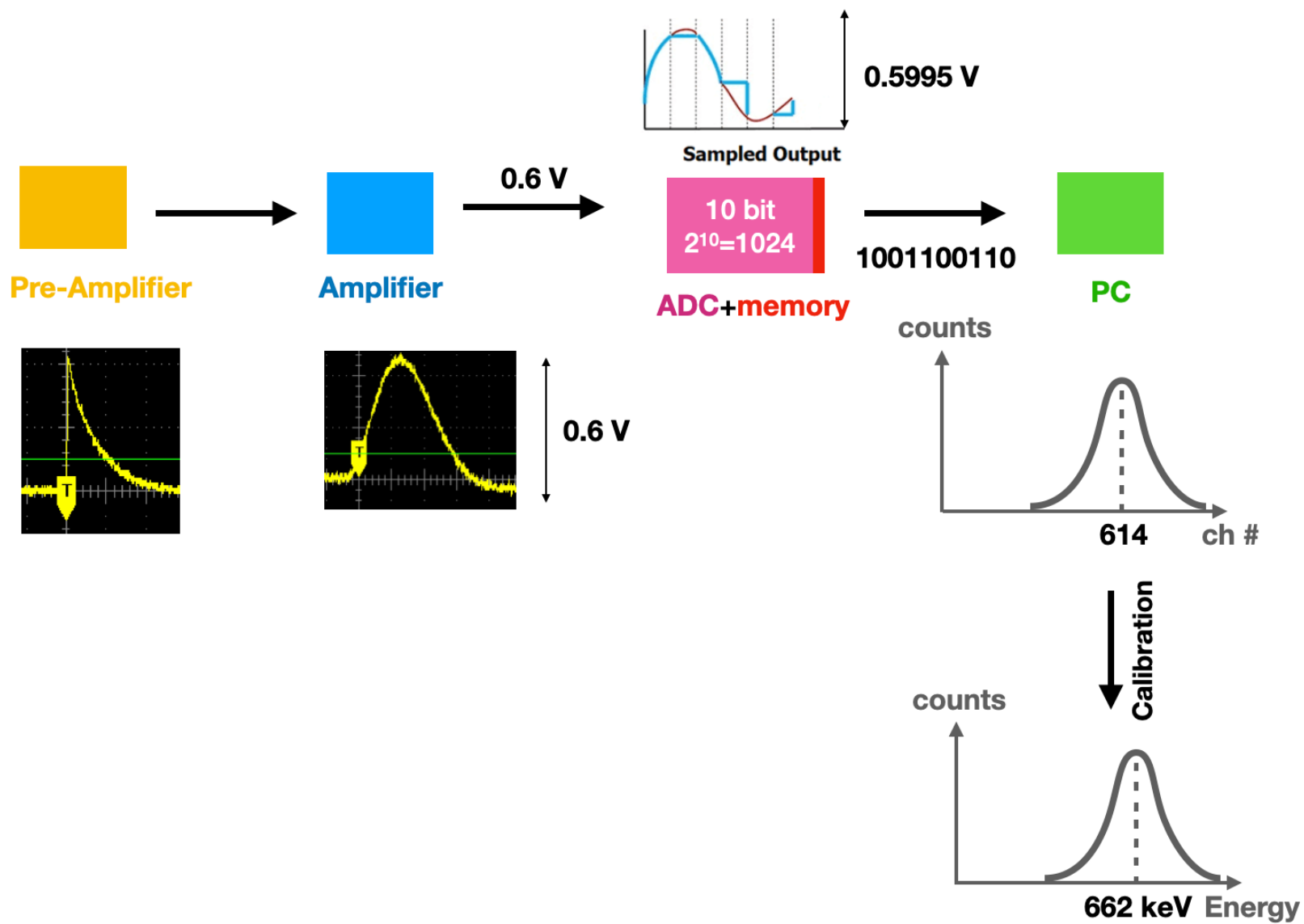
10 bit ADC=>  $2^{10}=1024$  channels (binary)

For simplicity We assume 1000 channels (decimals)

An input signal with an amplitude of 2.5 V will thus be converted to the digital number 250. It will be stored in channel number 250.

For a 150 mV pulse, we would find 15 and will be stored in ch#15

For a 6.62 V pulse, ADC will convert to the 662 digital number and will be stored in ch#662



# Types of ADC

## Peak-sensing

Maximum of a voltage is digitized.

Peak-sensing is used with slower signals which have already been integrated.

Example: A Photomultiplier in voltage mode —> PM of a NaI(Tl) scint. det.)

*ADC in the coming NaI experiment works in peak-sensing mode*

## Charge sensing

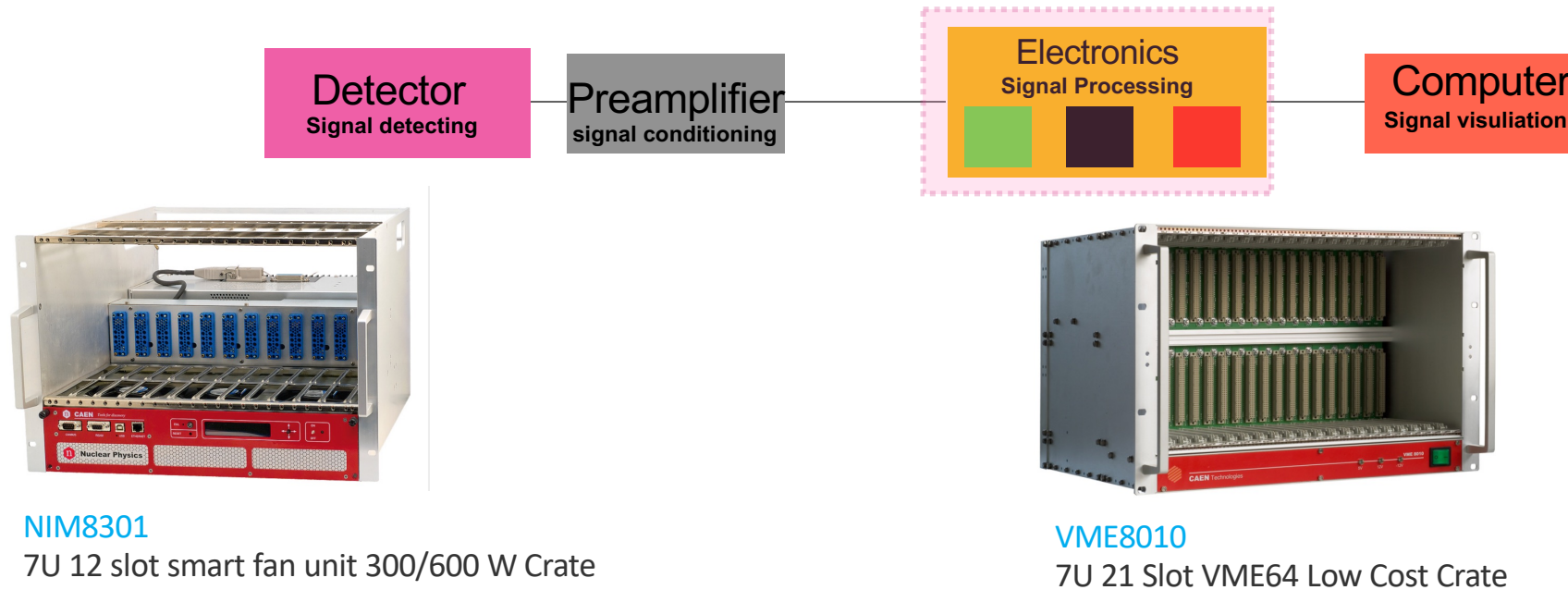
The total integrated current is digitized.

This mode is used current generating devices.

Example: A Photomultiplier in current mode —> PM of a plastic scint. det., fast detector)

# NIM and CAMAC Standards for Modular Instrumentation

*“Historically, these modules were commonly connected using NIM/CAMAC standards.”*



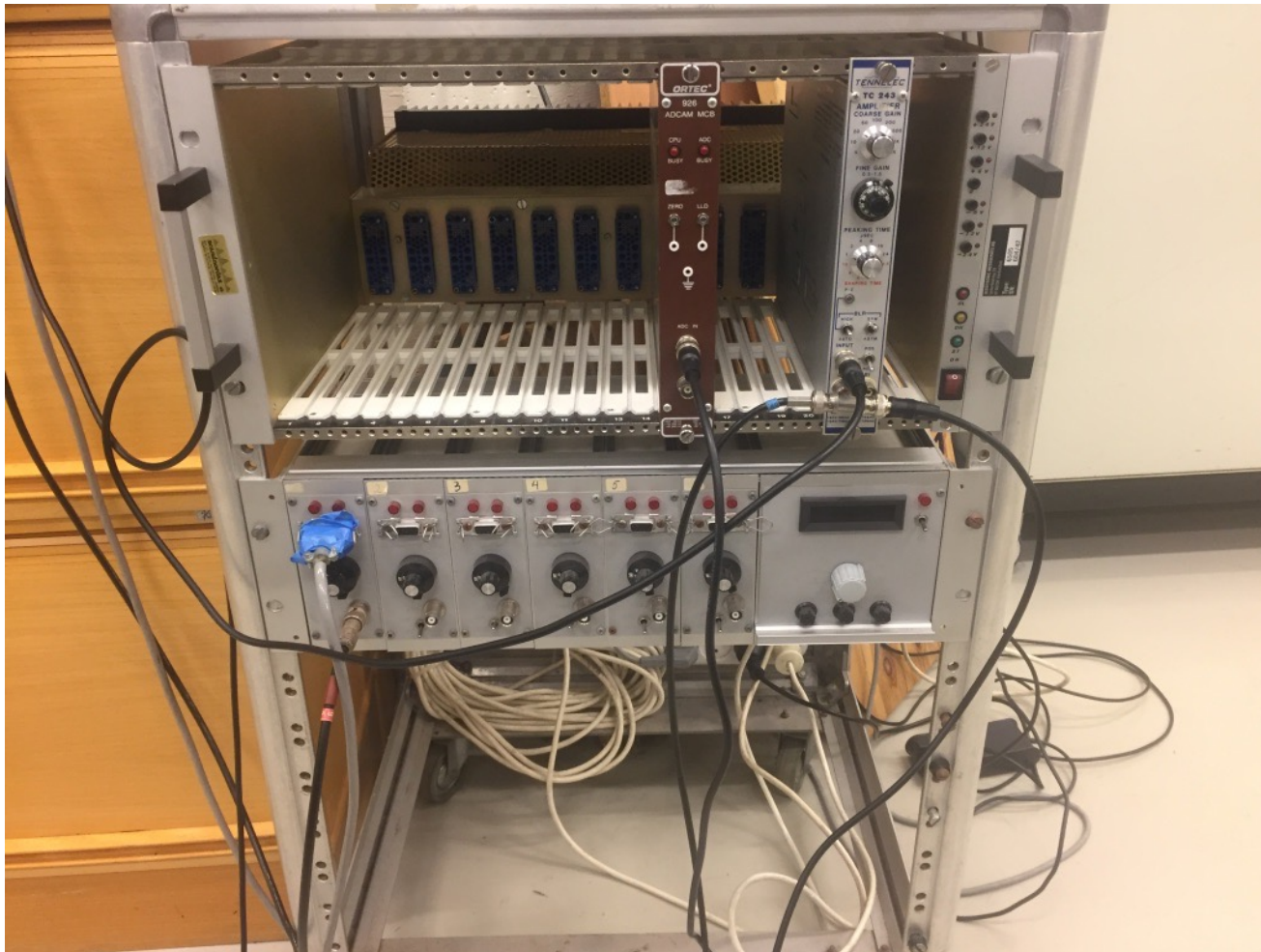
**NIM (Nuclear Instrument Module)**

**CAMAC (Computer Automated Measurement And Control) VME**

Detailed explanation about the standards:

- Chapter 18 in Leo
- Link below:

<https://www.ortec-online.com/-/media/ametektortec/other/electronics-standards-definitions.pdf?la=en&revision=0e444025-4952-429f-bebe-2a2a796d4543&hash=62BCDC0EB68CAF1F4F4CA5A8BC7412C3>



**CAEN, Italy:**  
[www.caen.it](http://www.caen.it)

#### Analog



ADCs (Peak Sensing)



Amplifiers (Fast)



Amplifiers (Spectroscopy)



Analog Pulse Processors



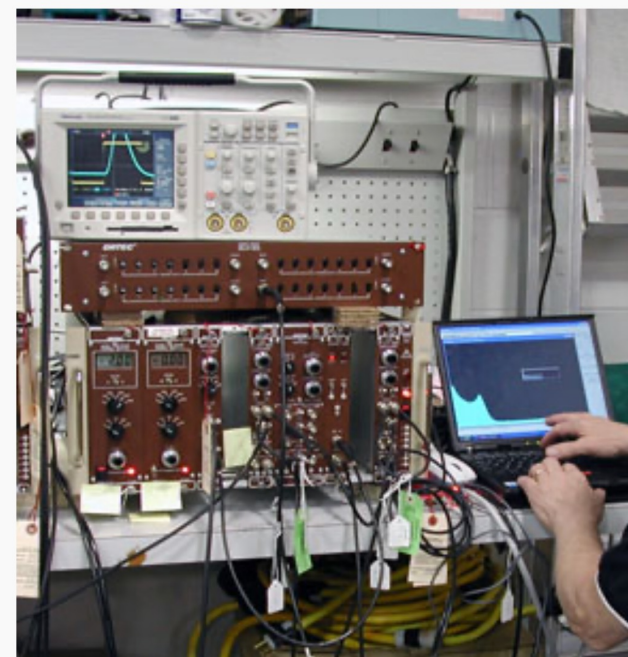
Digitizers



Discriminators

**ORTEC,USA:**  
[www.ortec-online.com](http://www.ortec-online.com)

ORTEC



electronics provide a critical role in a majority of gamma spectroscopy counting laboratories, physics research institutes and other gamma spectroscopy applications globally.

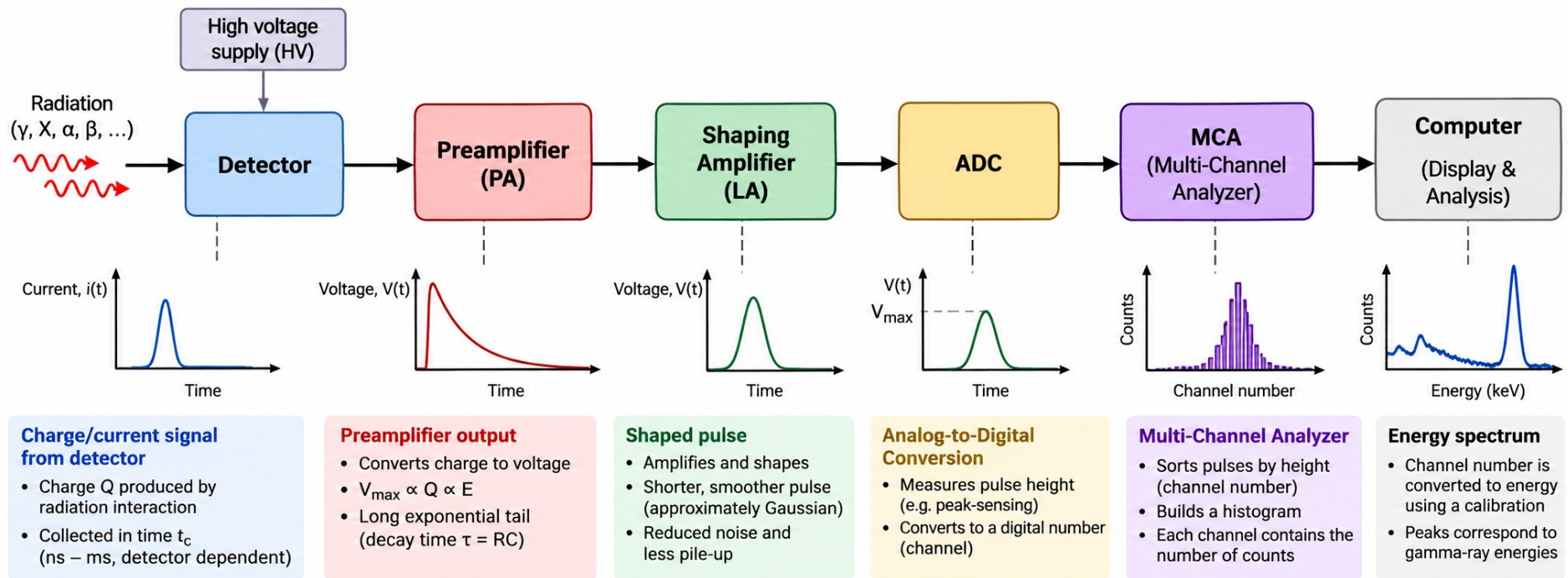
## **Course book Leo: Chapter 17: Timing Methods and Systems**

17.1 Walk and Jitter

17.2 Time-Pickoff Methods (Triggering)

17.3 Time-to-Amplitude Converter, TAC

17.4 Time-to-Digital Converter, TDC



# Questions to you

- What is a CR circuit and why is it used at the detector output?
- Explain main characteristics of a pulse signal after Preamplifier.
- What are the purposes of using Preamplifiers? Can they be placed far from the detectors? Explain your reasoning.
- Which type of detectors do need preamplification and which do not? Explain your reasoning.
- Signals from detectors have to be processed. What are our reasons for amplifying and shaping signals?
- Why is the electronic noise very important for germanium detectors but not very vital for NaI(Tl) detectors?