Method for digital particle spectrometry

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The goals of Analog Signal Processing

- Signal amplification
- Signal filtering
- Analyzing of signals amplitude distribution
- Analyzing of signals timing distribution

Analog unit and its function

- Spectroscopy amplifier
- Fast amplifier
- Constant fraction discriminator
- Discriminator with fix threshold
- Amplitude to digital converter
- Time to digital converter
- Delay unit

Use of Digital Signal Processing in different fields

- Communication
- Radar and sonar
- Music
- Mobile phone
- Geology
- Photography
- Medicine

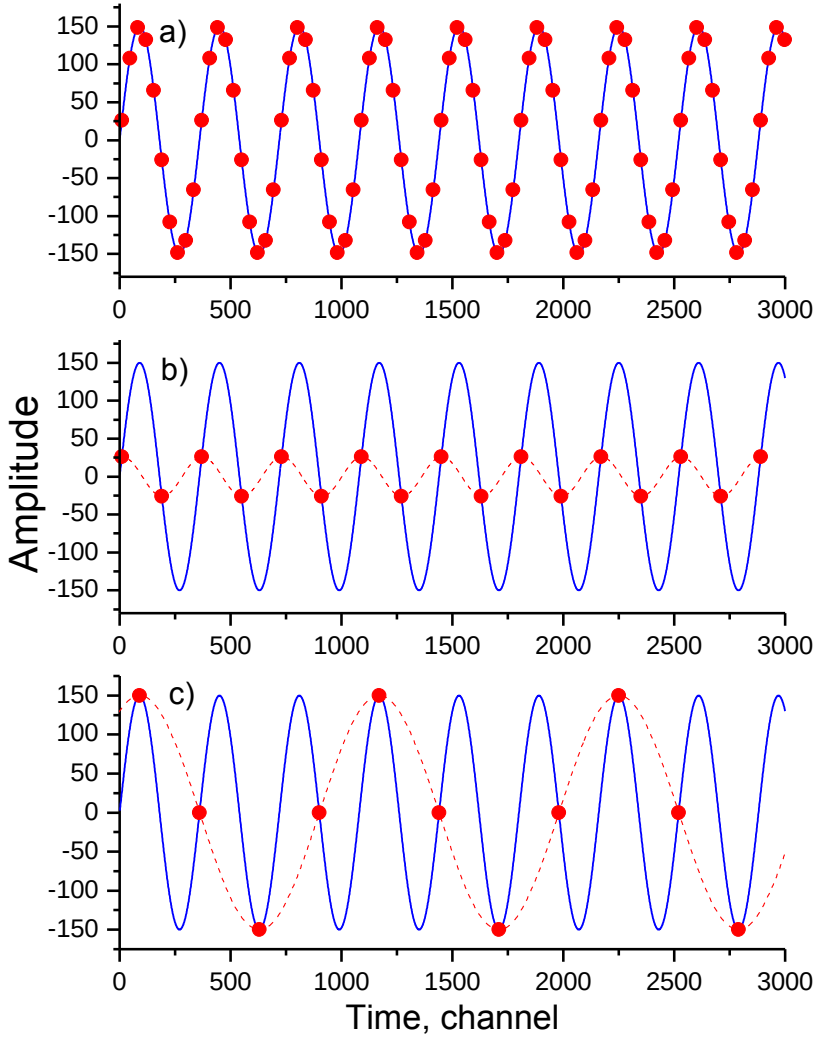
Advantages of Digital Signal Processing

- Stability
- Resettability
- Depth of evaluation
- Low mass of the equipment

Why Digital Spectrometry wasn't used in nuclear physics before?

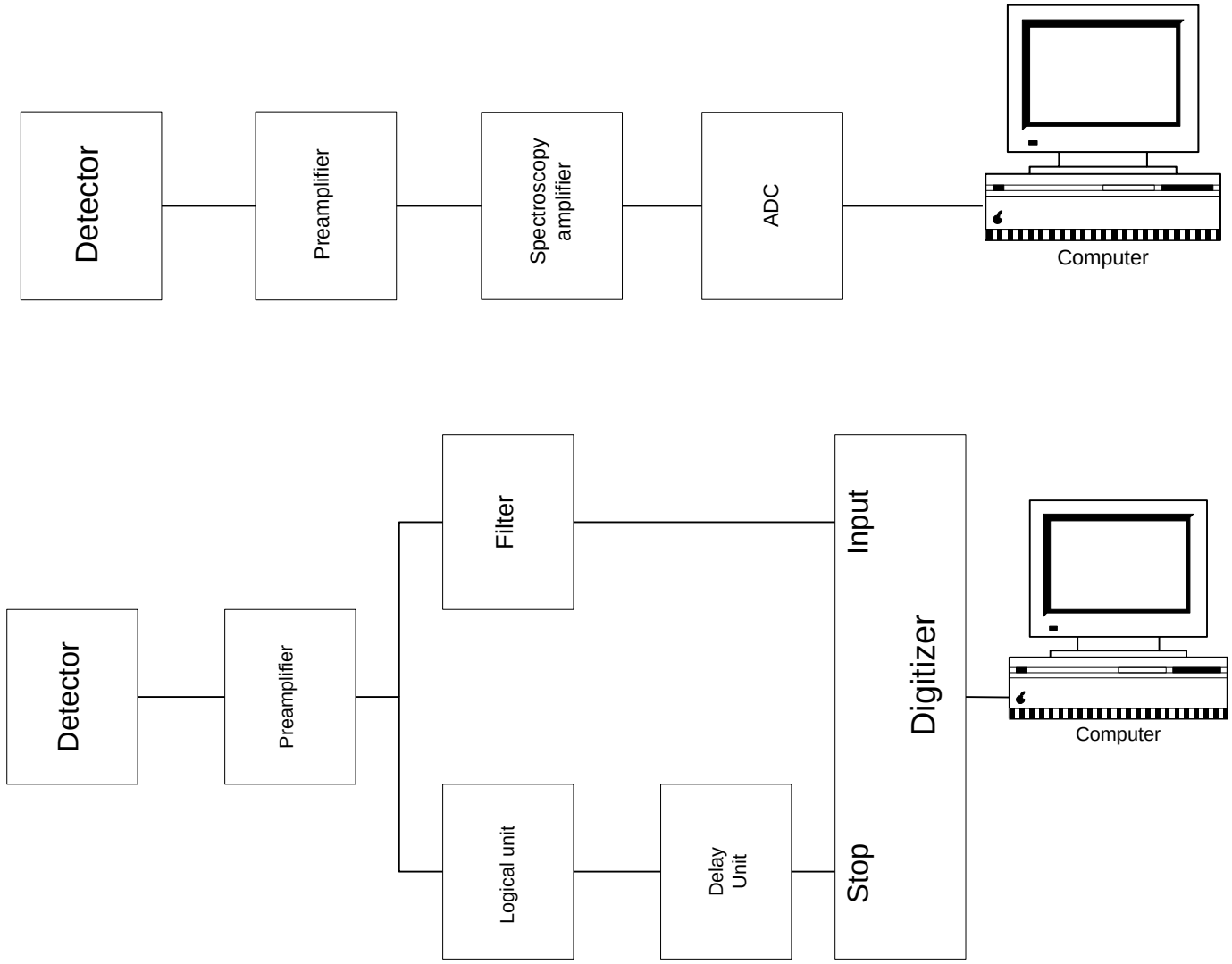
- ✓ Signals in nuclear physics are fast, non periodical, contain specific noise.
- ✓ Big volume of information

Nyquist frequency

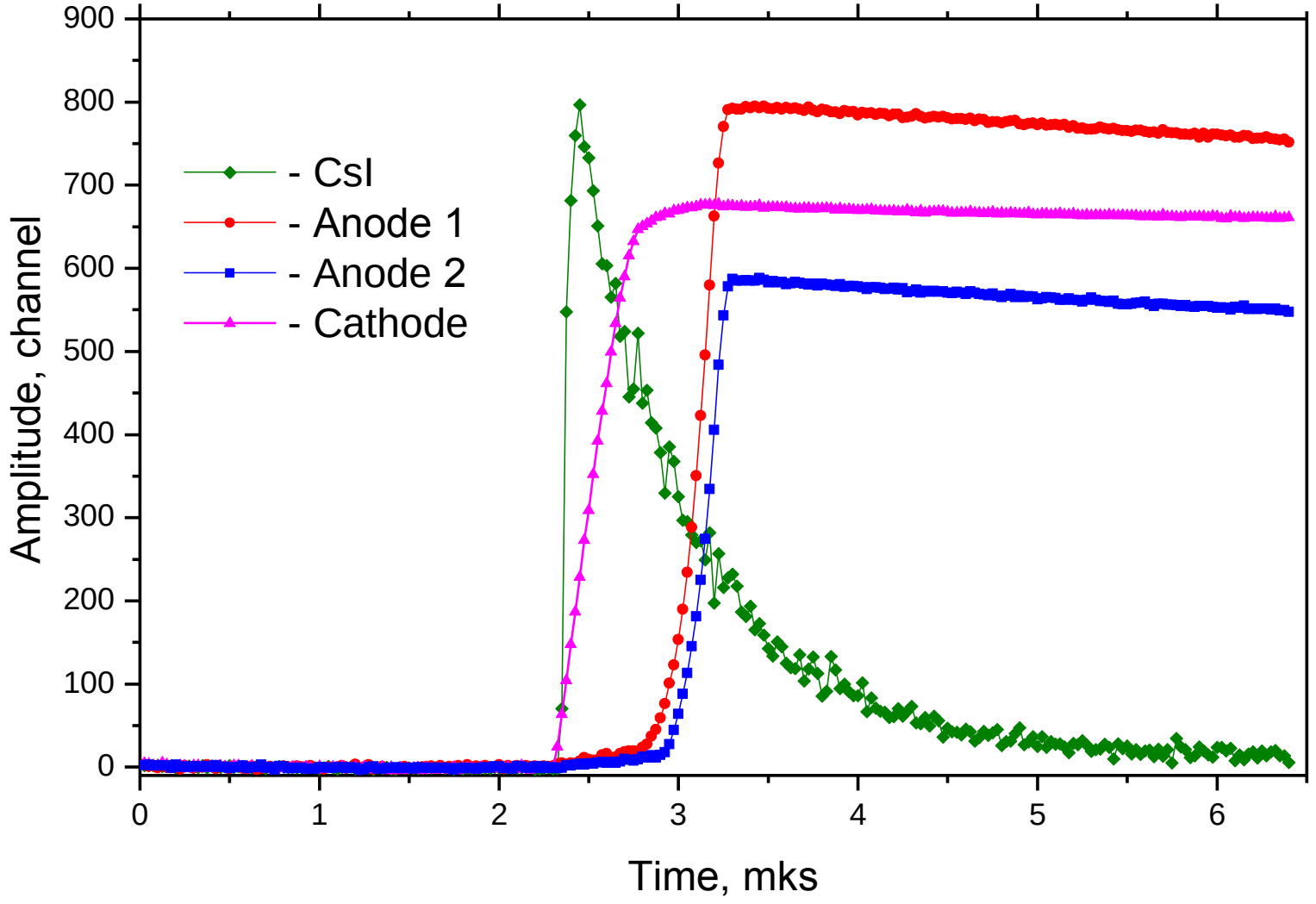


To properly digitize signal with frequency F, it must be sampled at 2F samples/sec or higher.

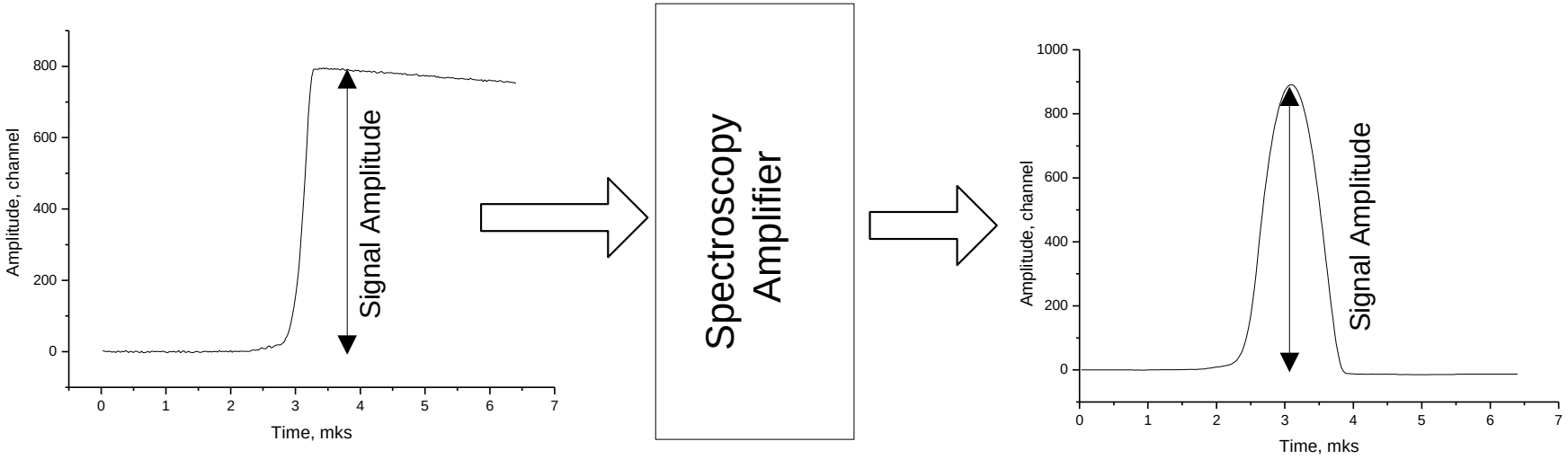
Analog and digital spectrometric channel



How do the digital signals from the particle detector look like?

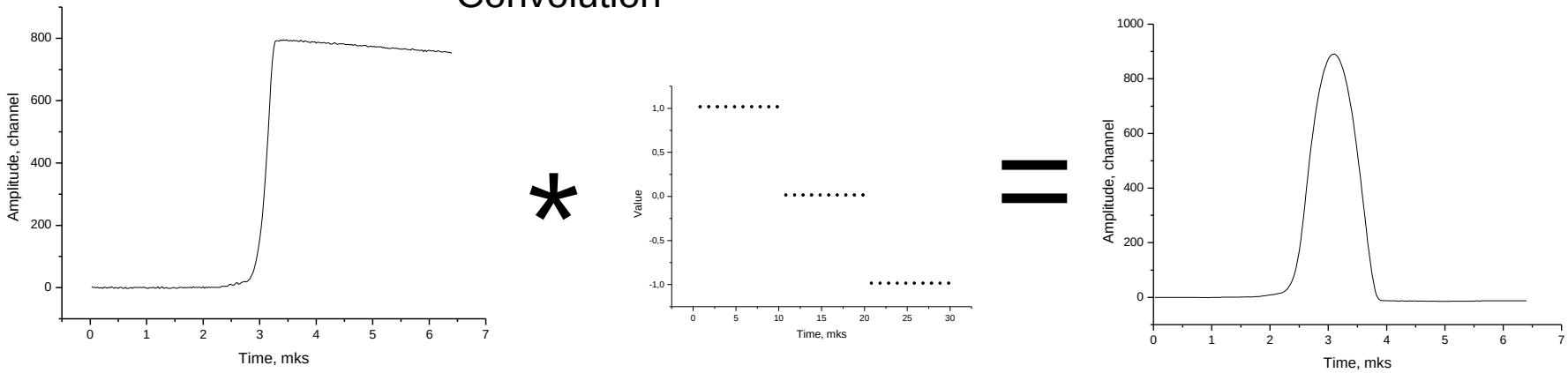


Analog spectroscopy amplifier

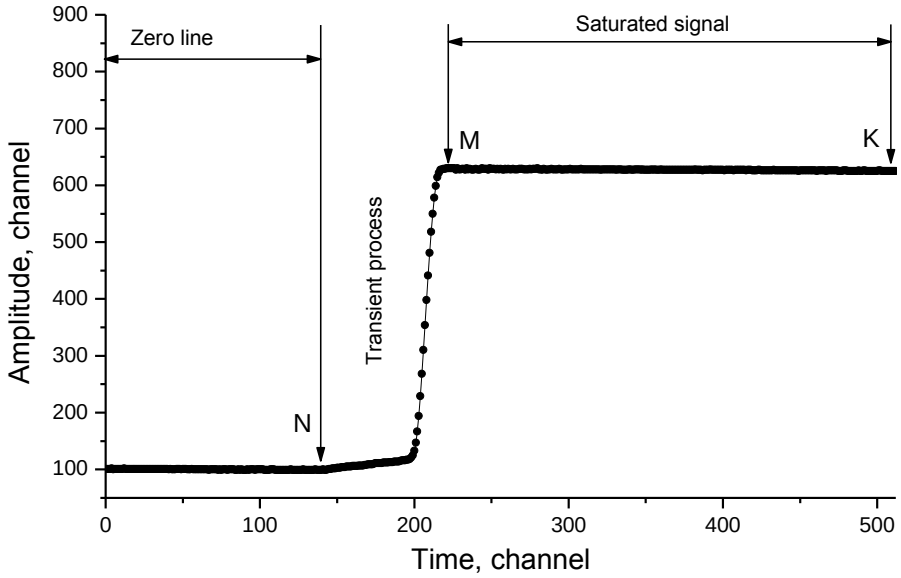


Digital spectroscopy amplifier

Convolution

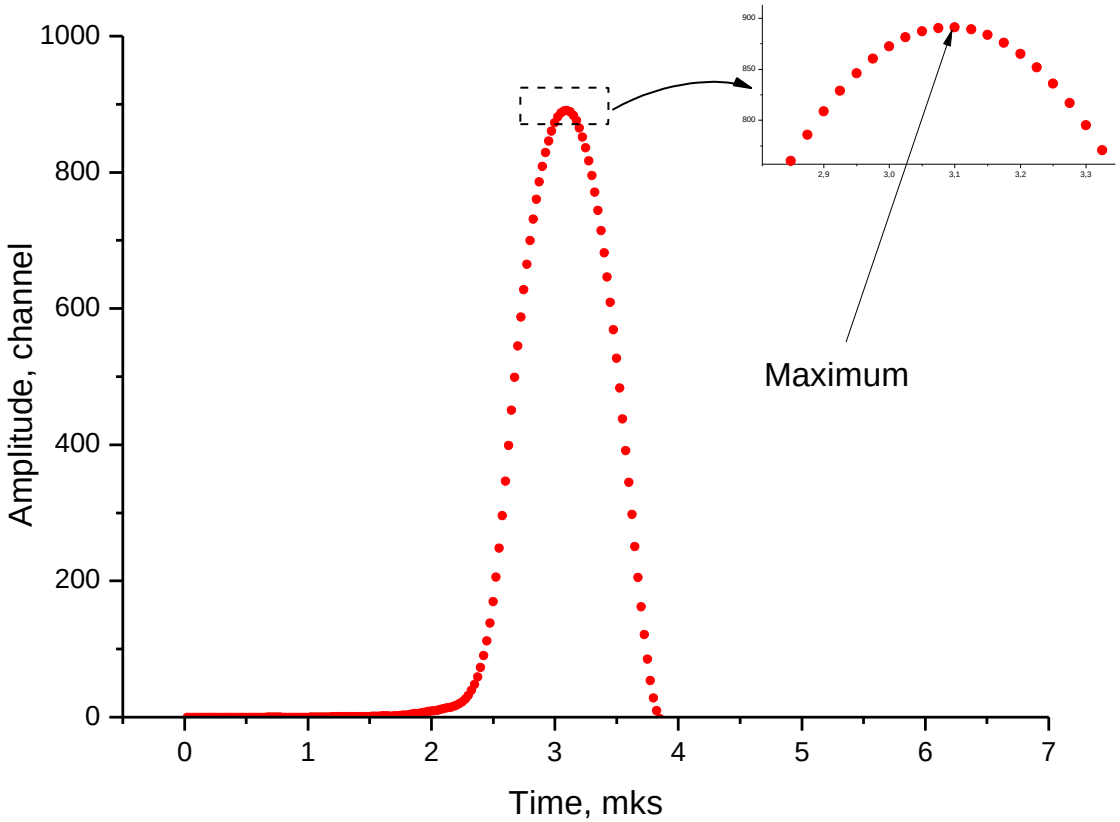


Another method for amplitude determination

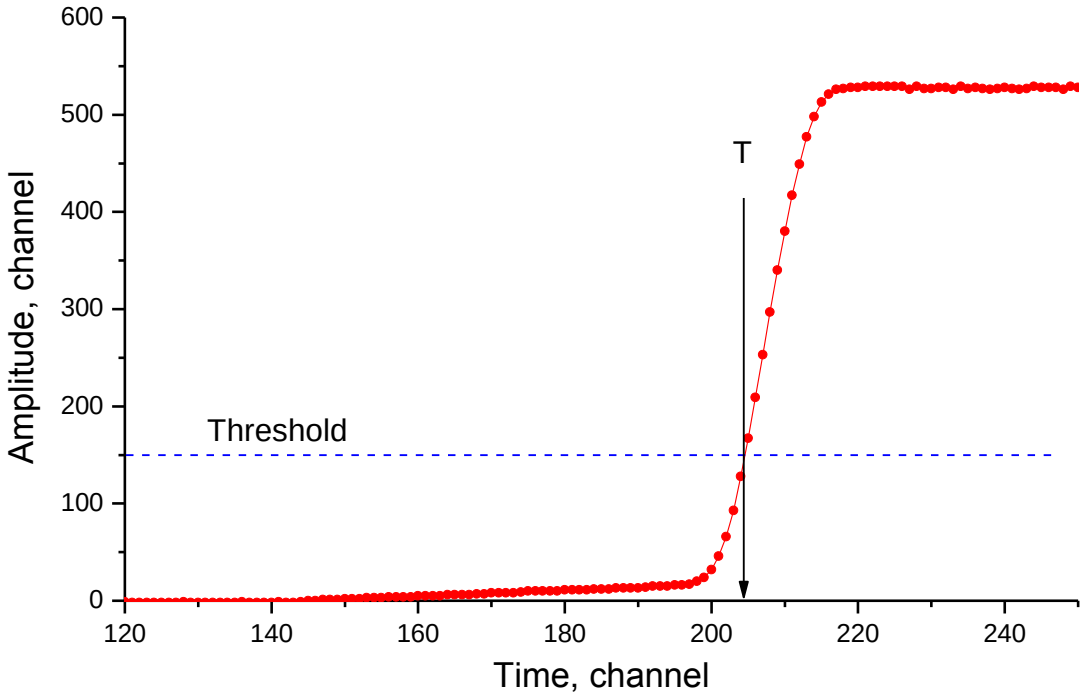


$$A = \frac{\sum_{i=M}^{K} s(i)}{K - M + 1} - \frac{\sum_{i=1}^{N} s(i)}{N}$$

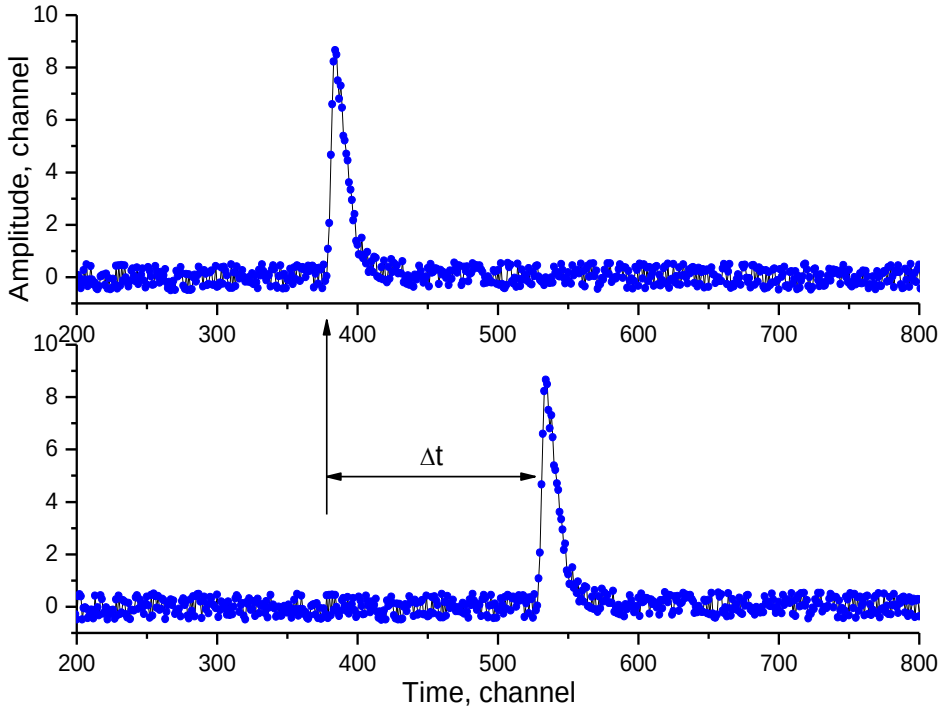
Amplitude Digital Converter (ADC)



Discriminator with fix threshold



Delay unit



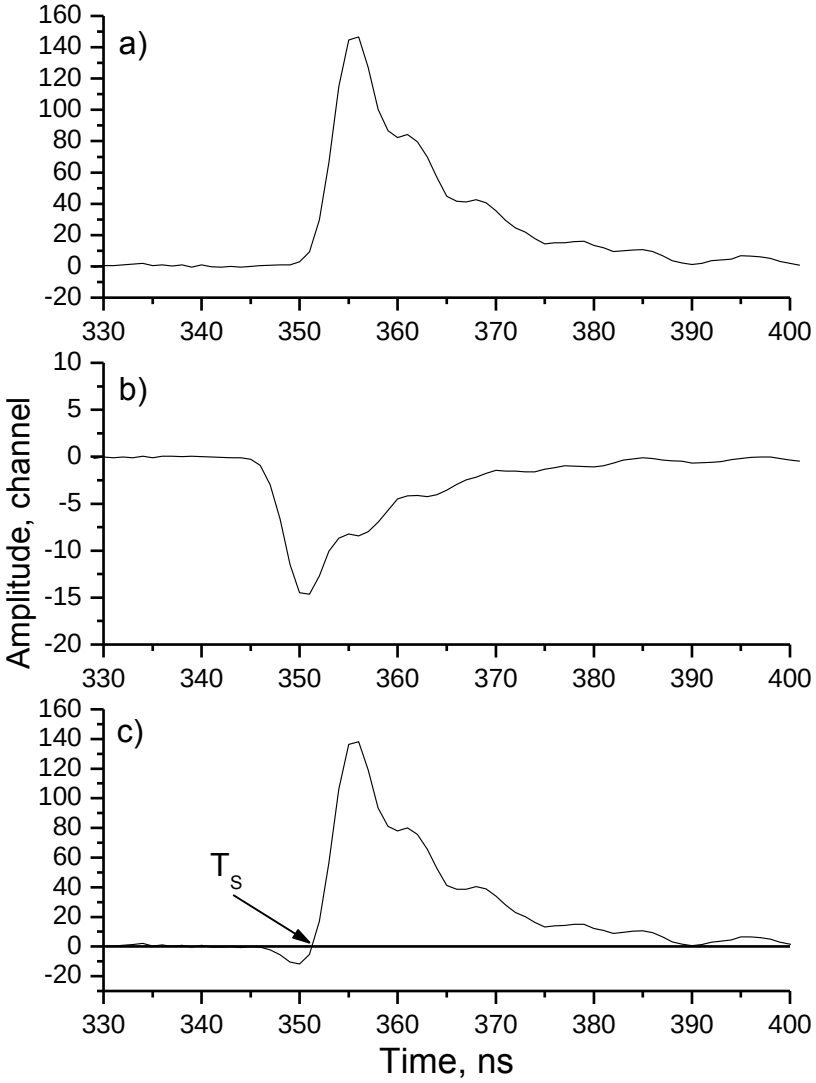
Initial signal

Delayed signal

You can transfer signal to any time without any distortion of it shape.

You can transfer signal not only to the right but to the left too!

Constant Fraction (CF) discriminator



Delayed initial signal

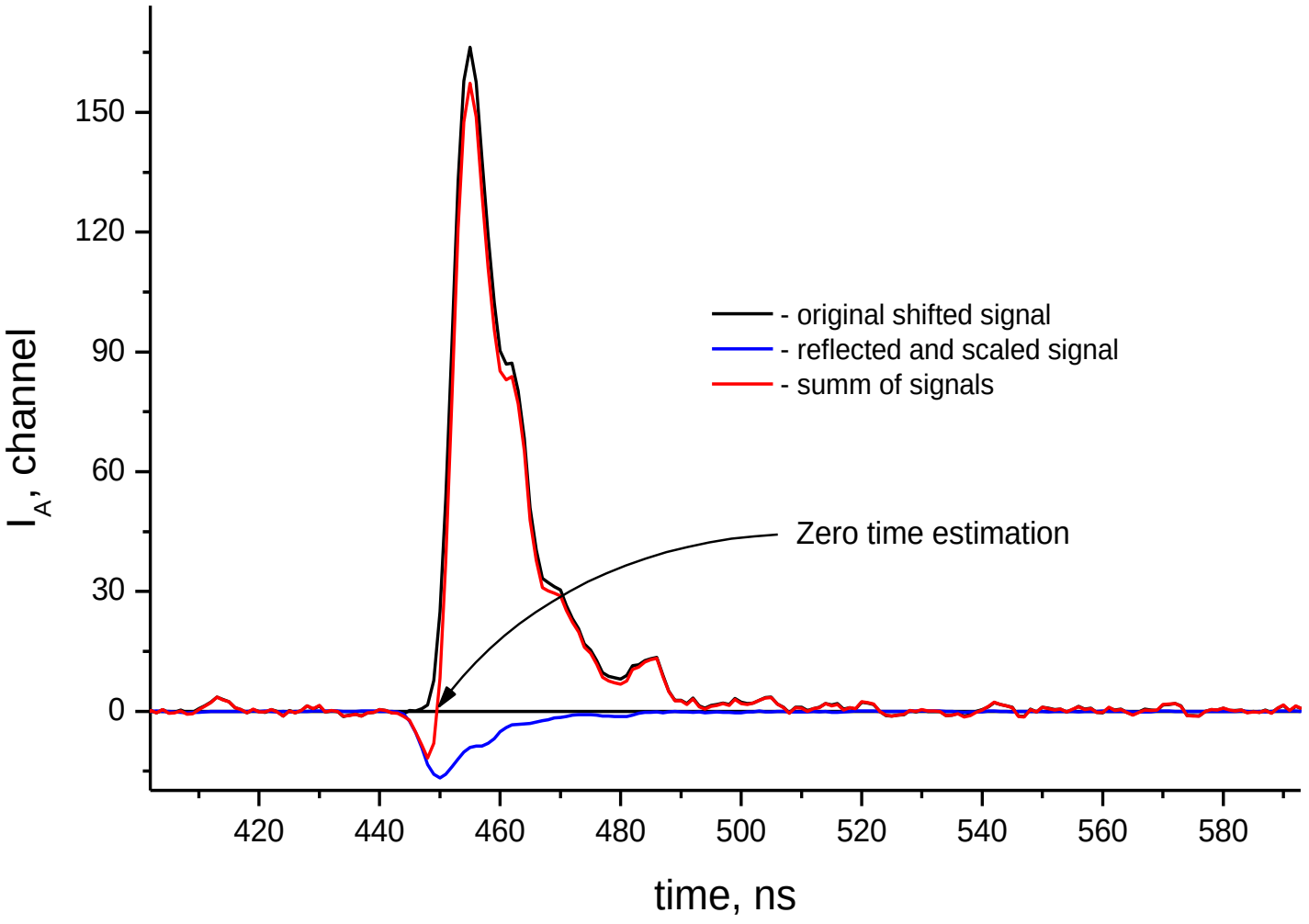
+

Inversed and attenuated initial signal

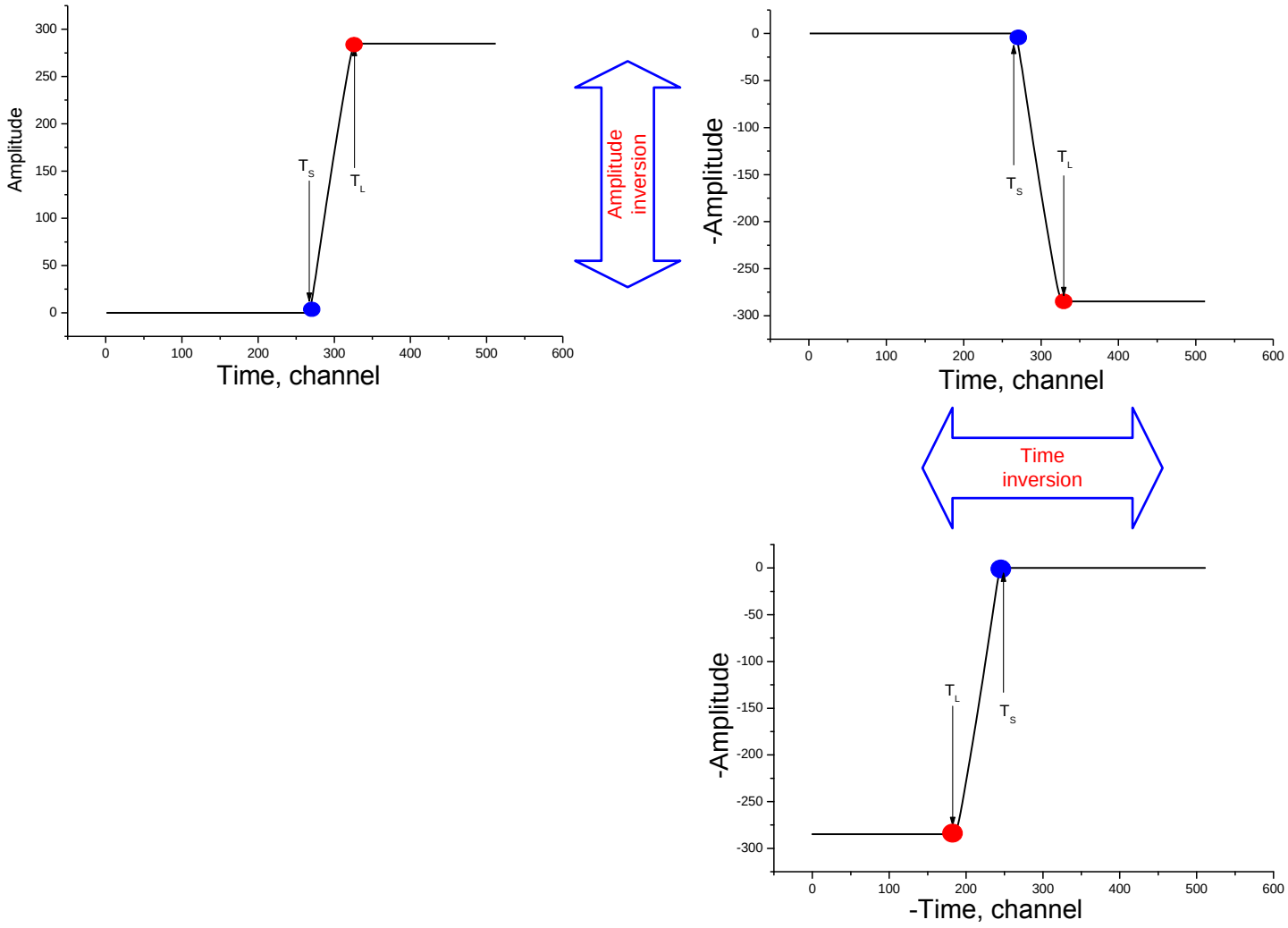
=

Sum of signals

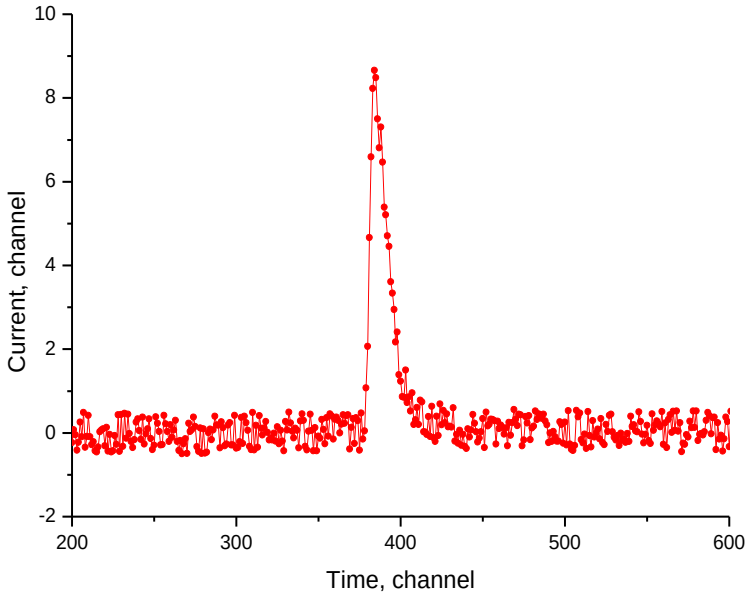
Determination of the signal appearance time with a constant fraction discriminator for digital signals.

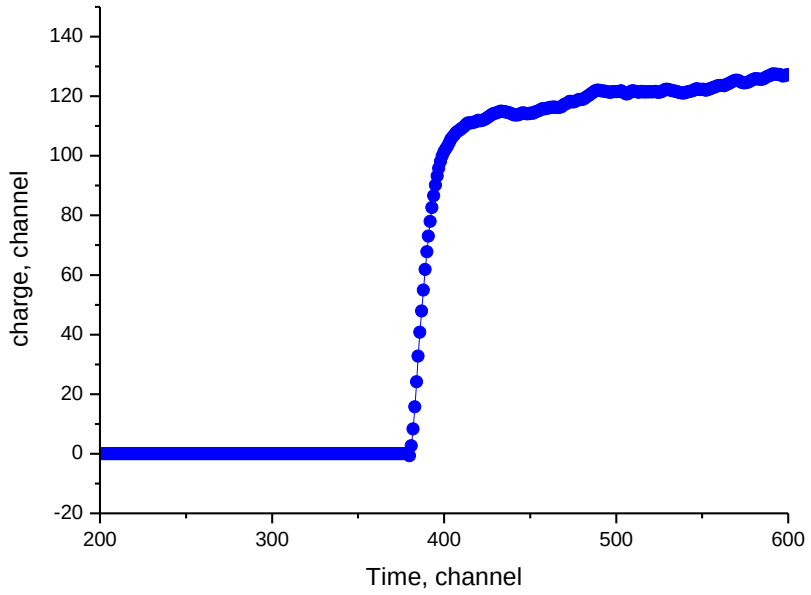


New possibility for signal evaluation

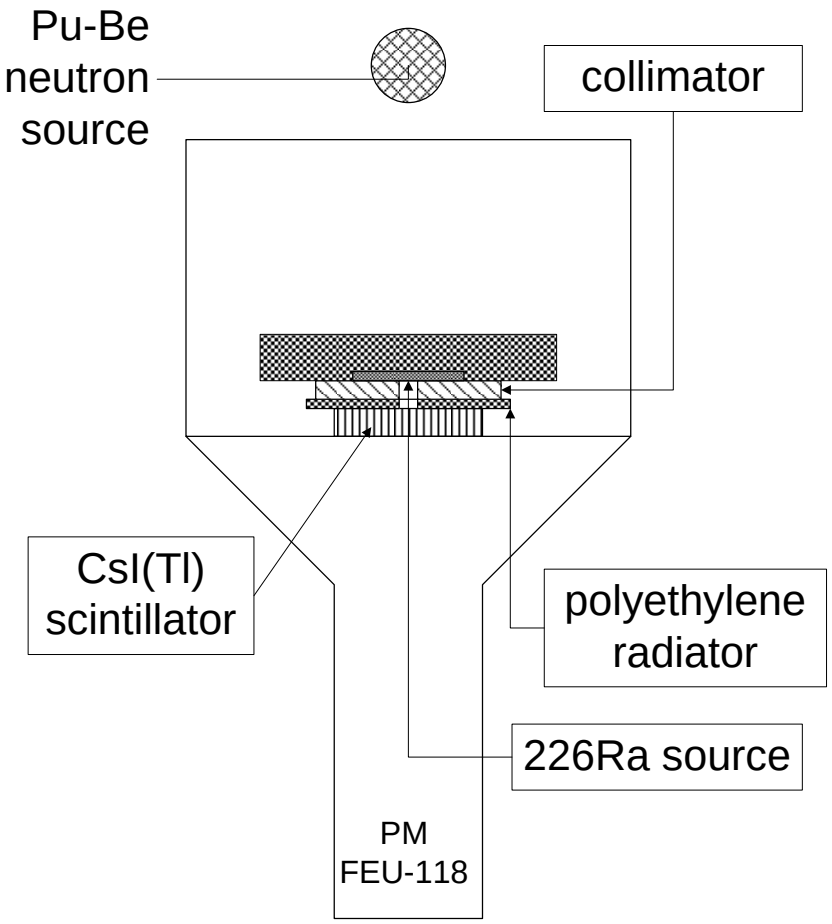


Charge determination

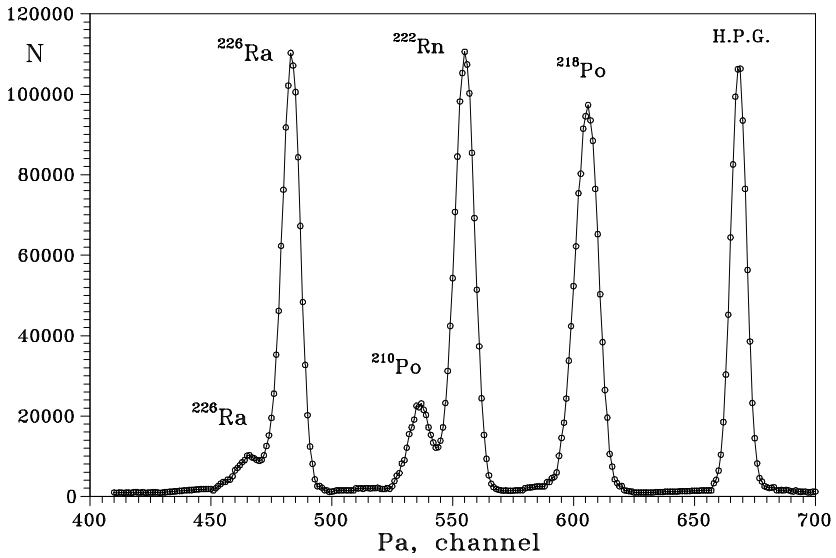


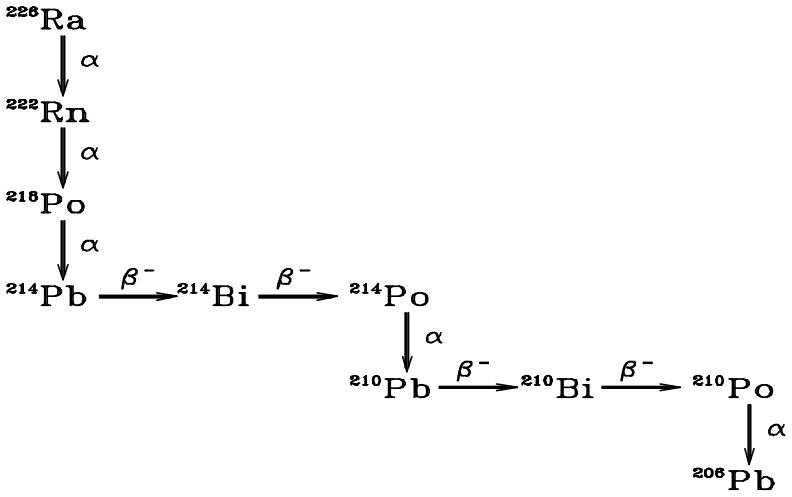


CsI(Tl) scintillator

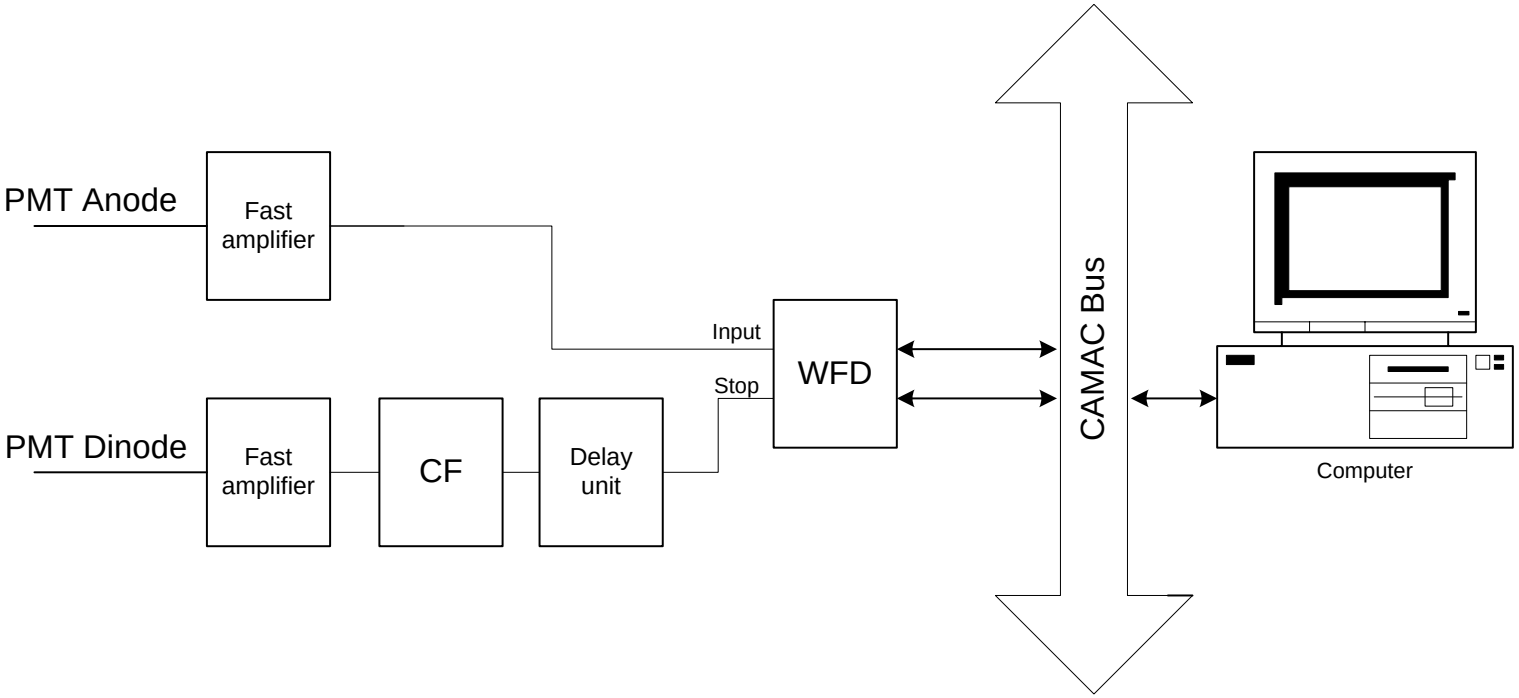


^{226}Ra decay scheme

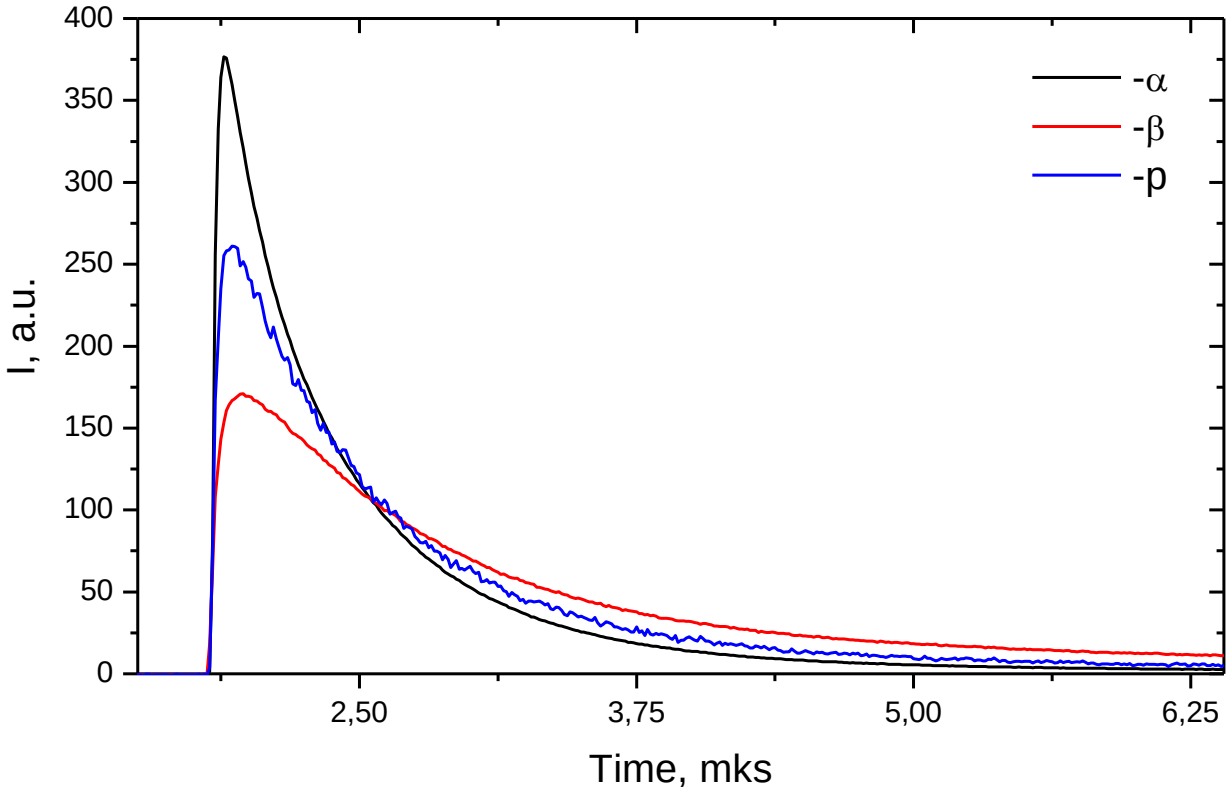




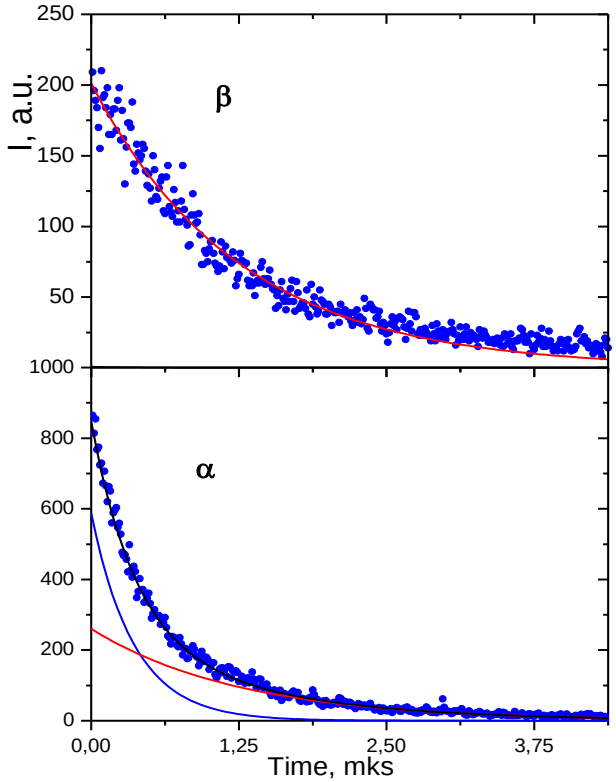
CsI(Tl). Spectrometer

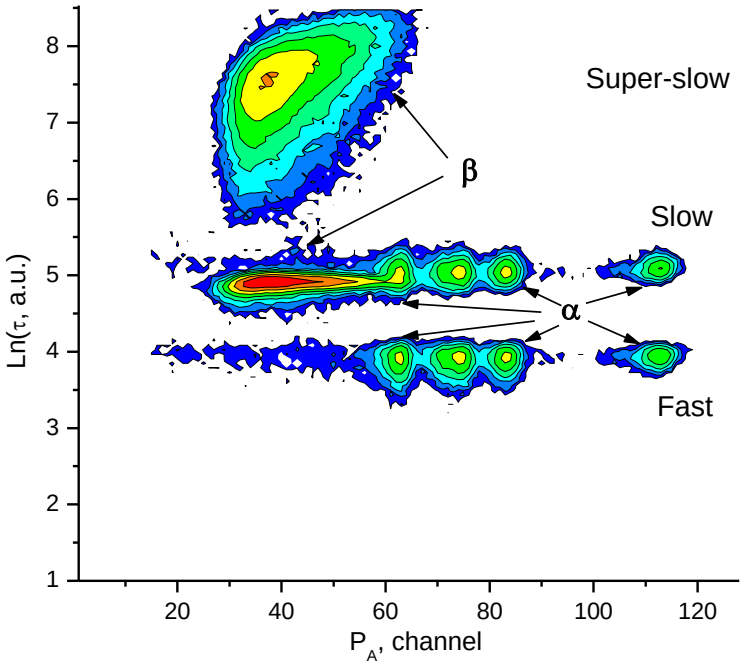


CsI(Tl). Pulse shape for different particles



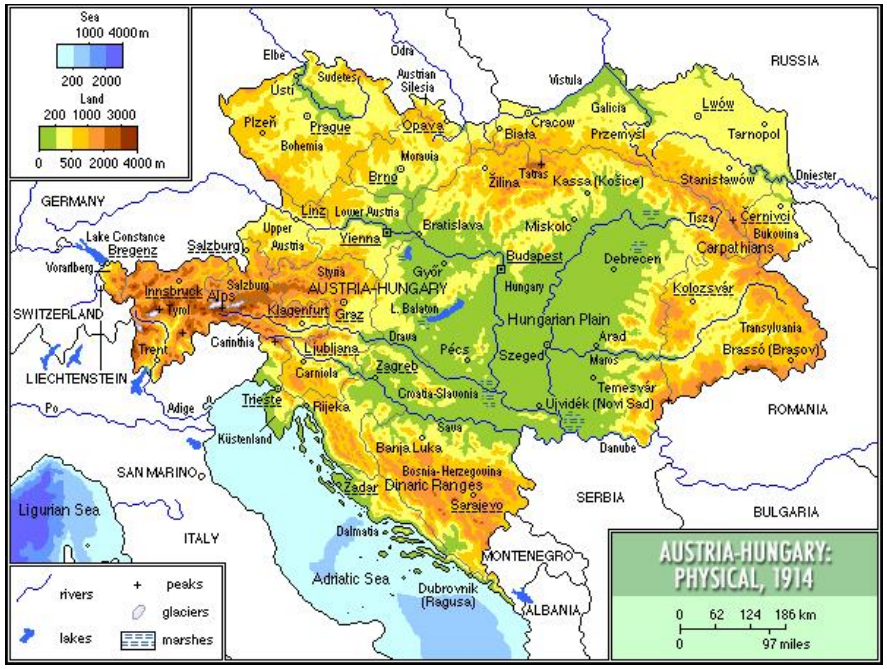
Decomposition of CsI(Tl) signal

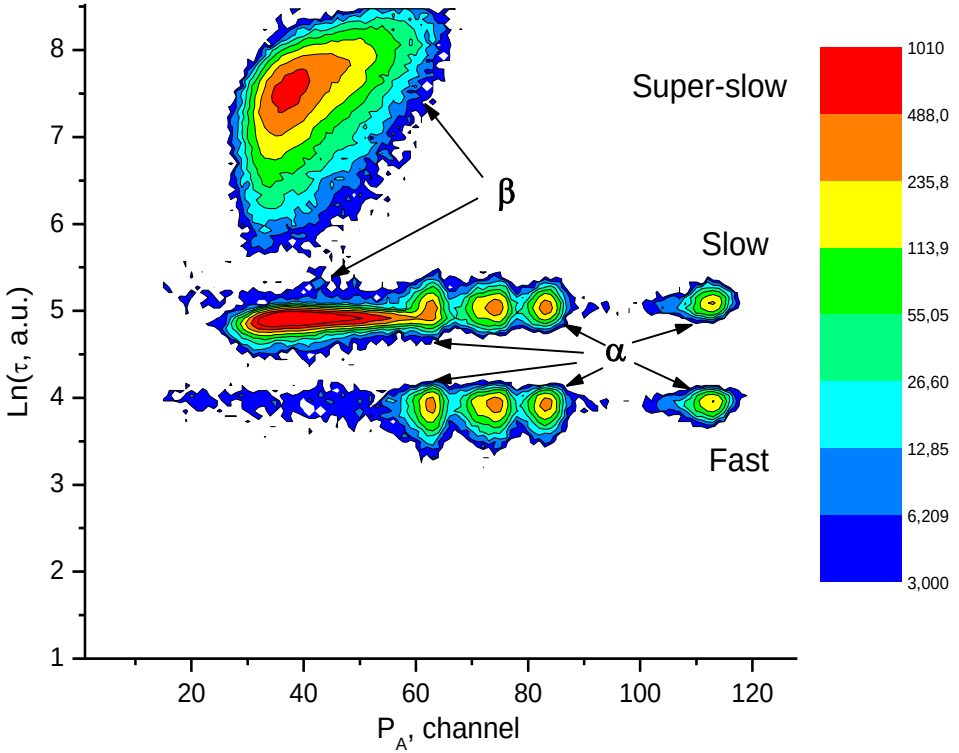




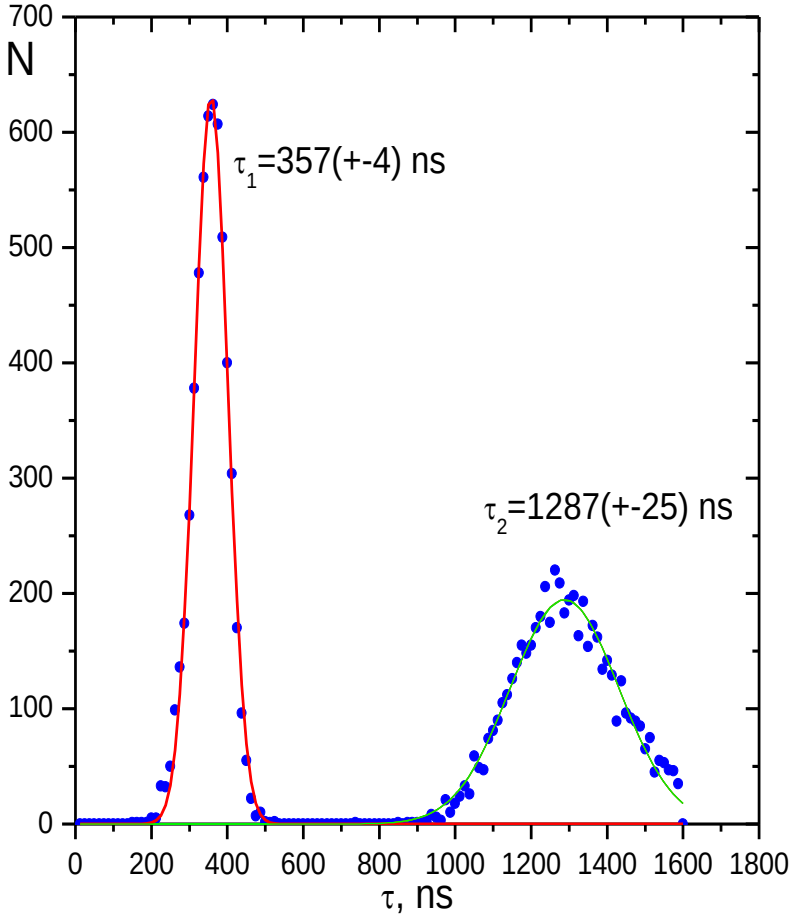
$$L(t) = \left(S_{Fast} / \tau_{Fast}\right) * \exp\left(-(t - T_0) / \tau_{Fast}\right) + \left(S_{Slow} / \tau_{Slow}\right) * \exp\left(-(t - T_0) / \tau_{Slow}\right)$$

How to understand 3D spectra?



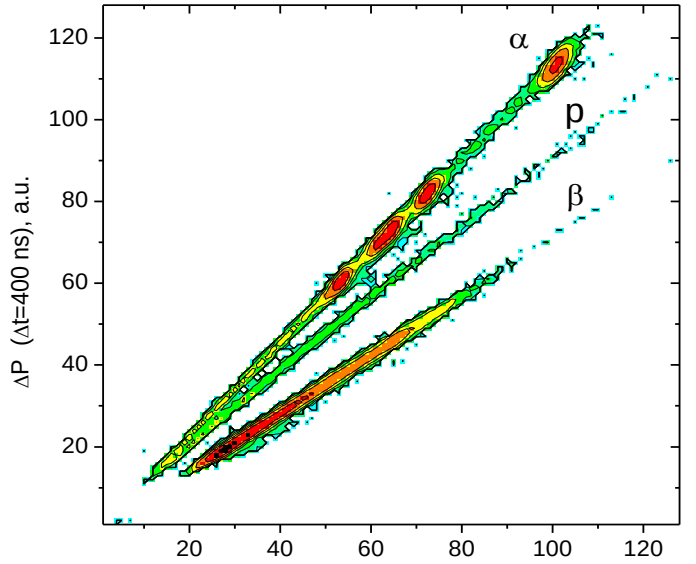


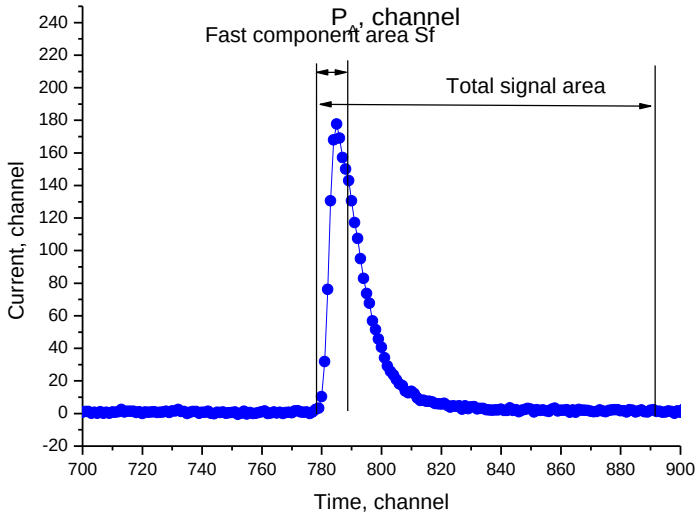
Luminescence decay time for the CsI(Tl) scintillator



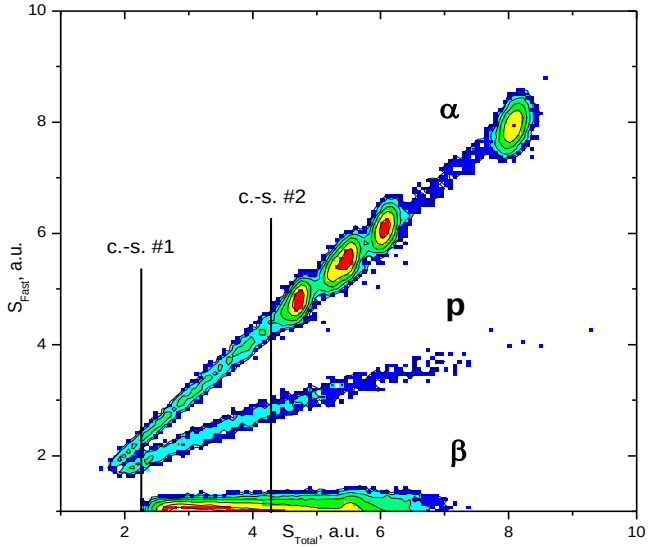
CsI(Tl). Two methods of particle identification

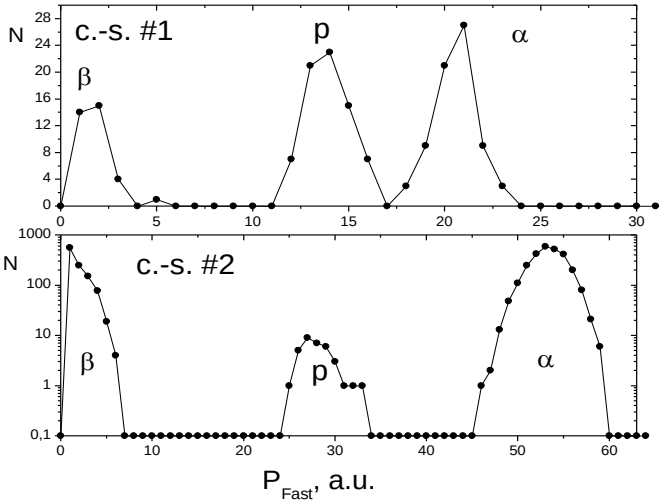
Integration in the window



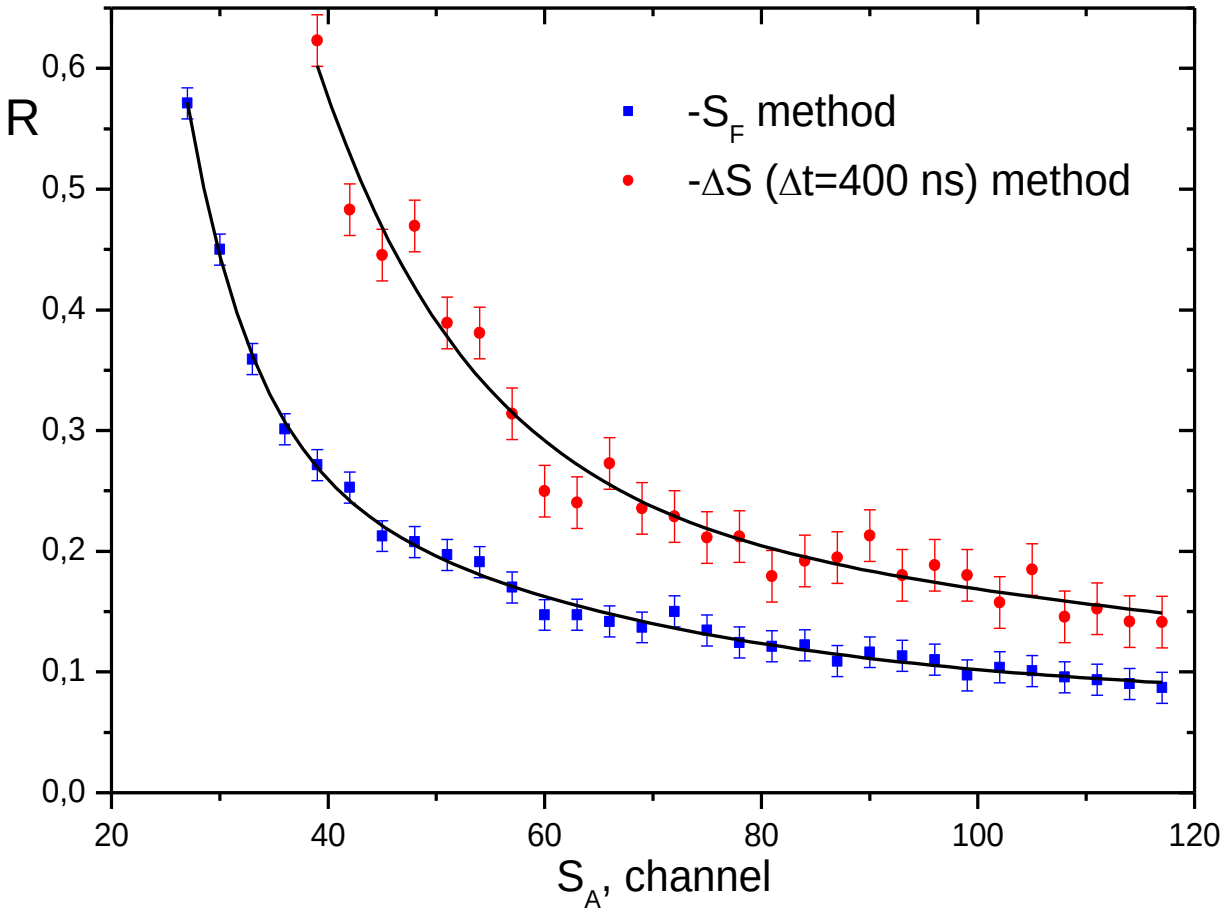


Fast component area



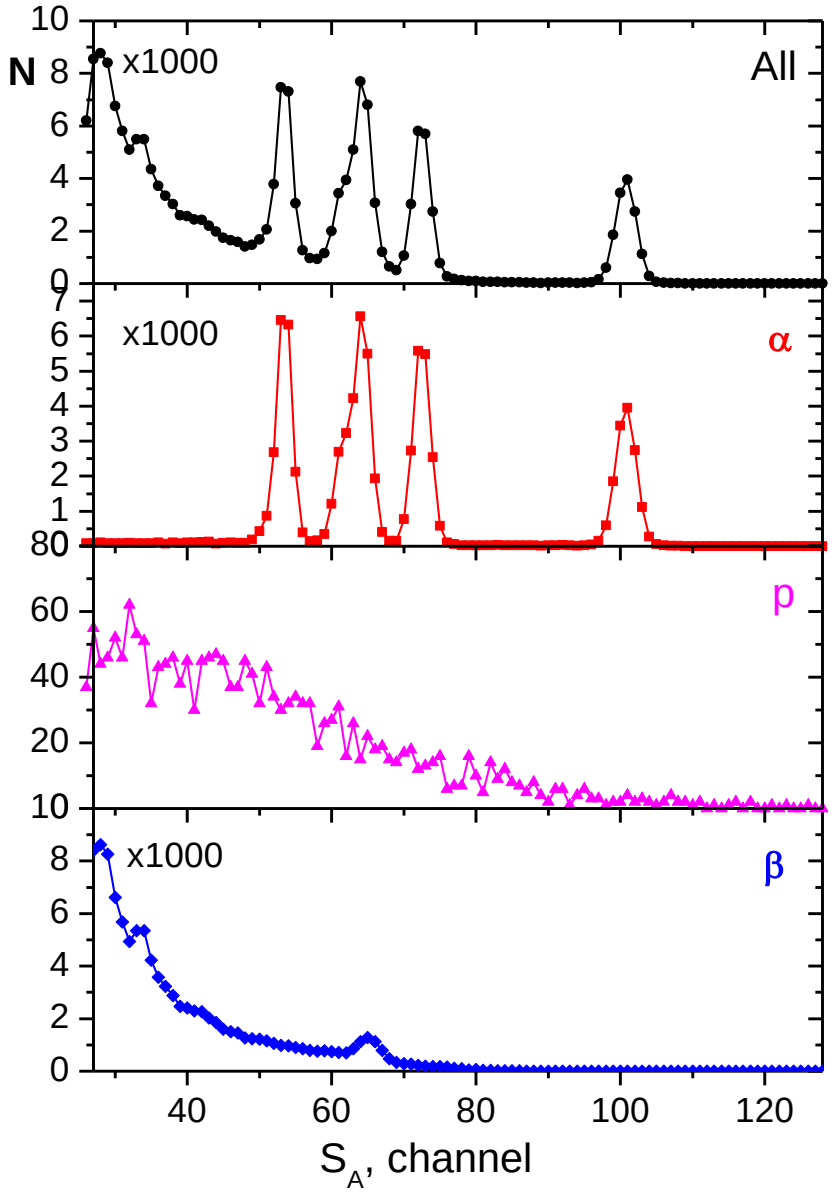


CsI(Tl). Comparison of two methods

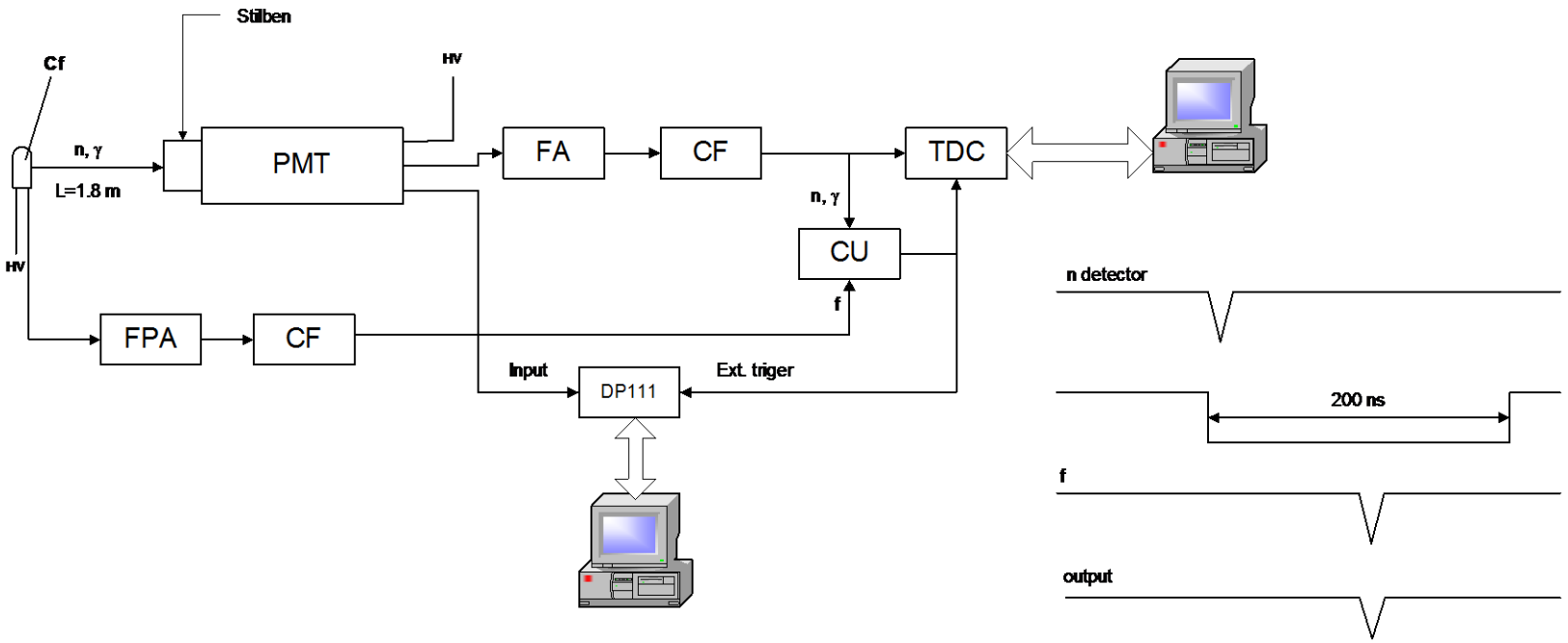


$$R = \frac{\sigma_\alpha + \sigma_p}{S_\alpha - S_\rho}$$

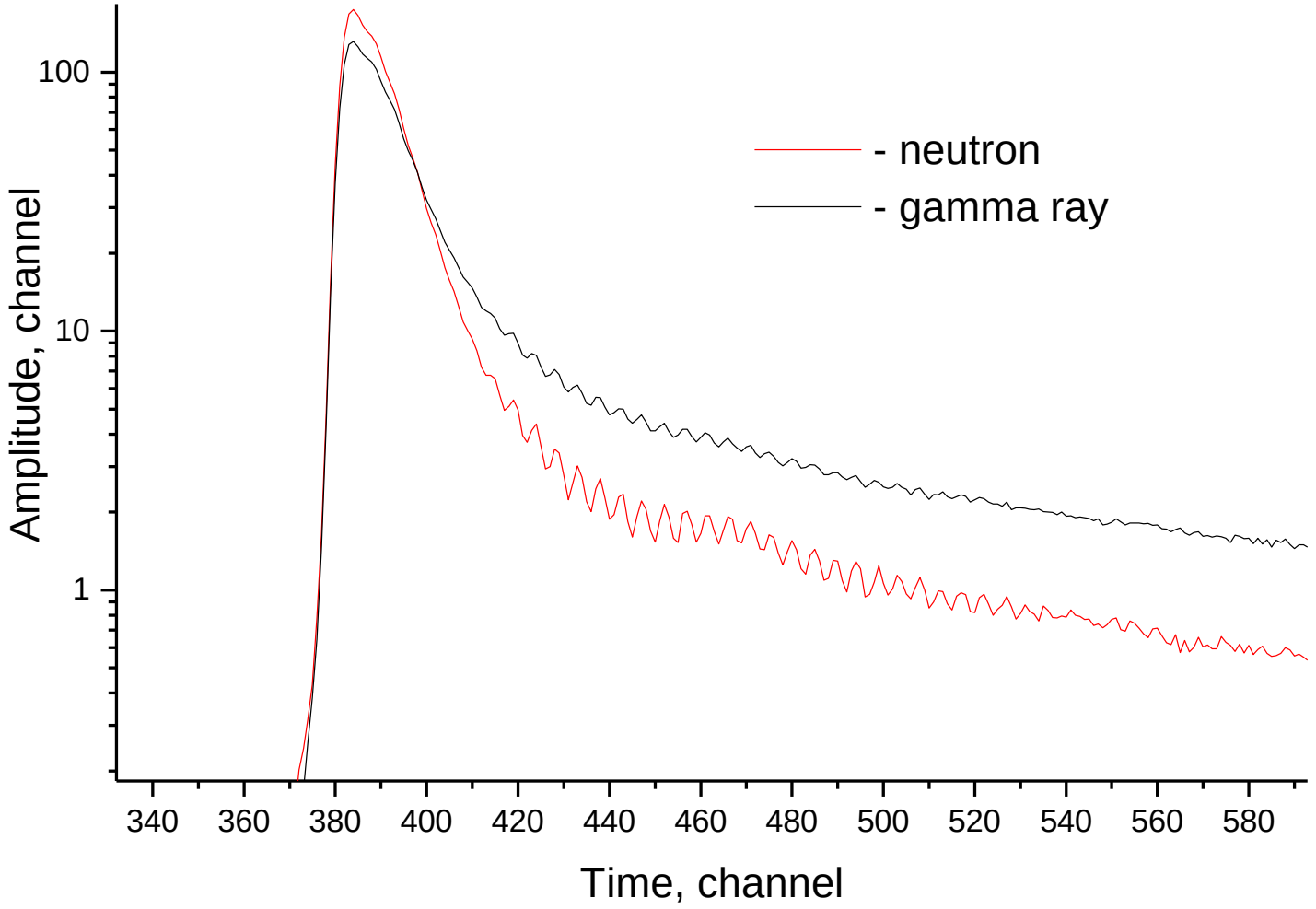
The CsI(Tl) scintillator for particle identification



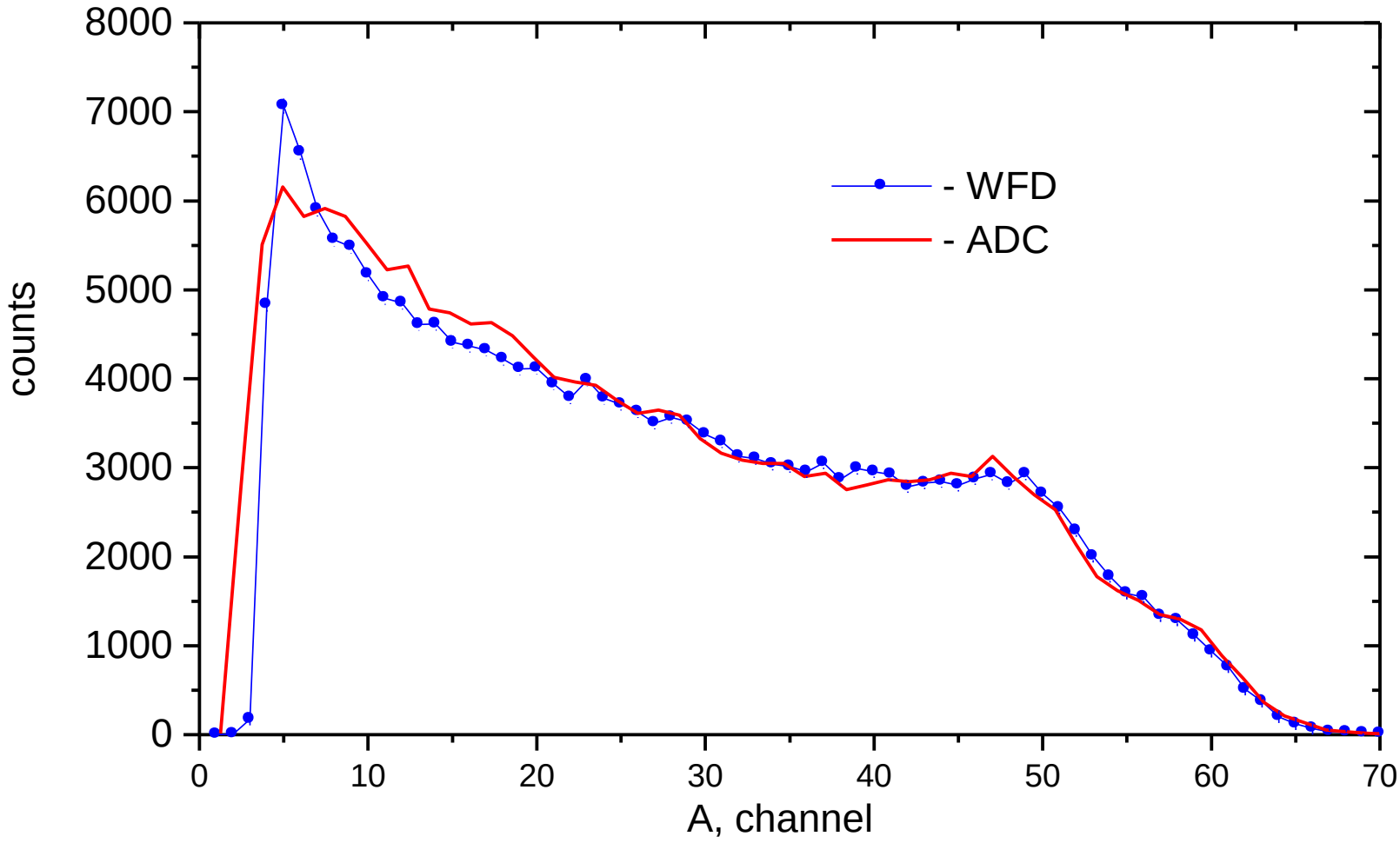
Block scheme of a spectrometer based on a stilbene crystal



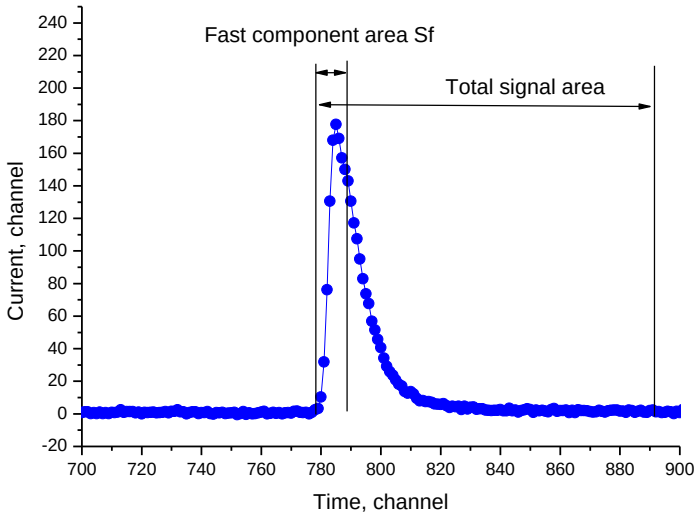
Stilbene. Pulse shape for proton and electron with light yield of 1 MeVee

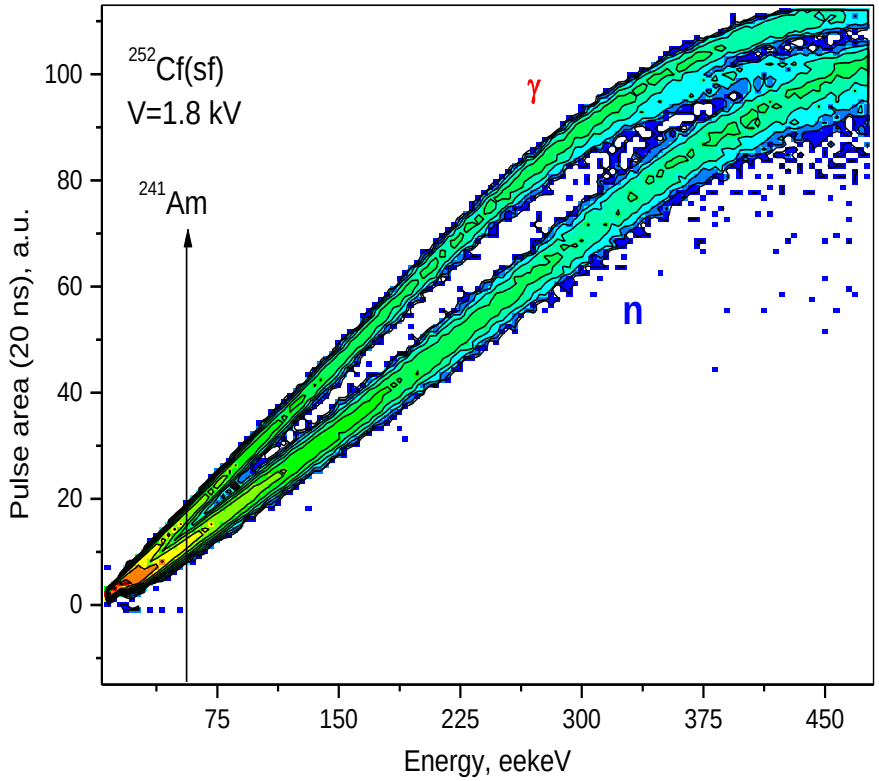


Stilbene. Amplitude distributions. Digitizer vs conventional electronics

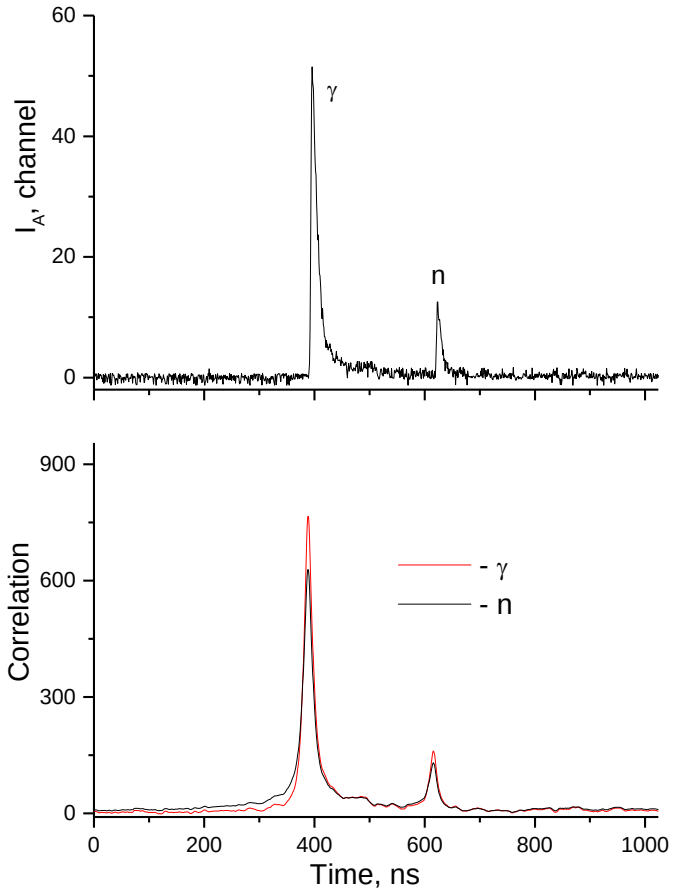


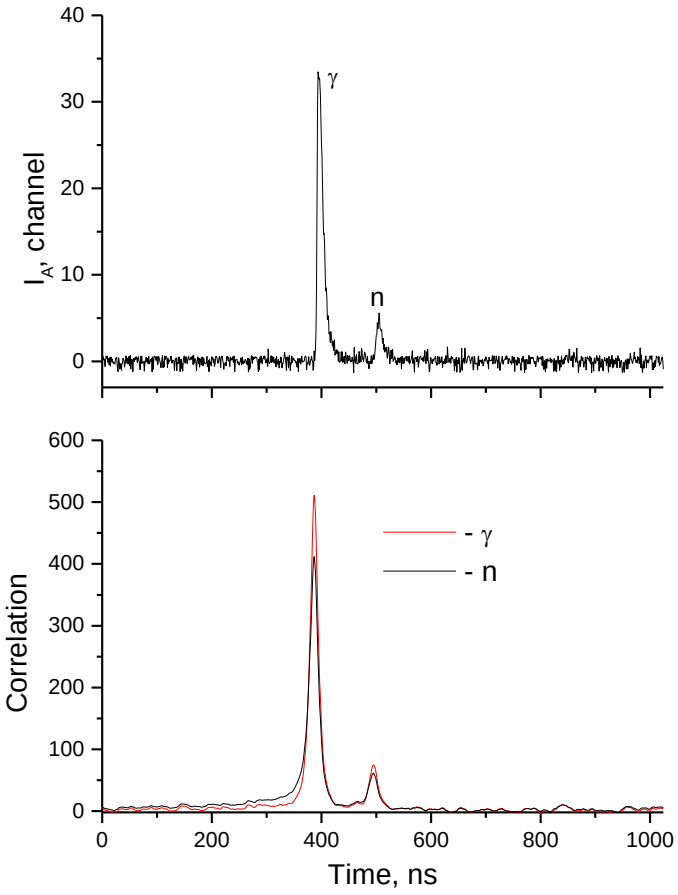
Stilbene. Pulse shape (PS): Fast versus total area



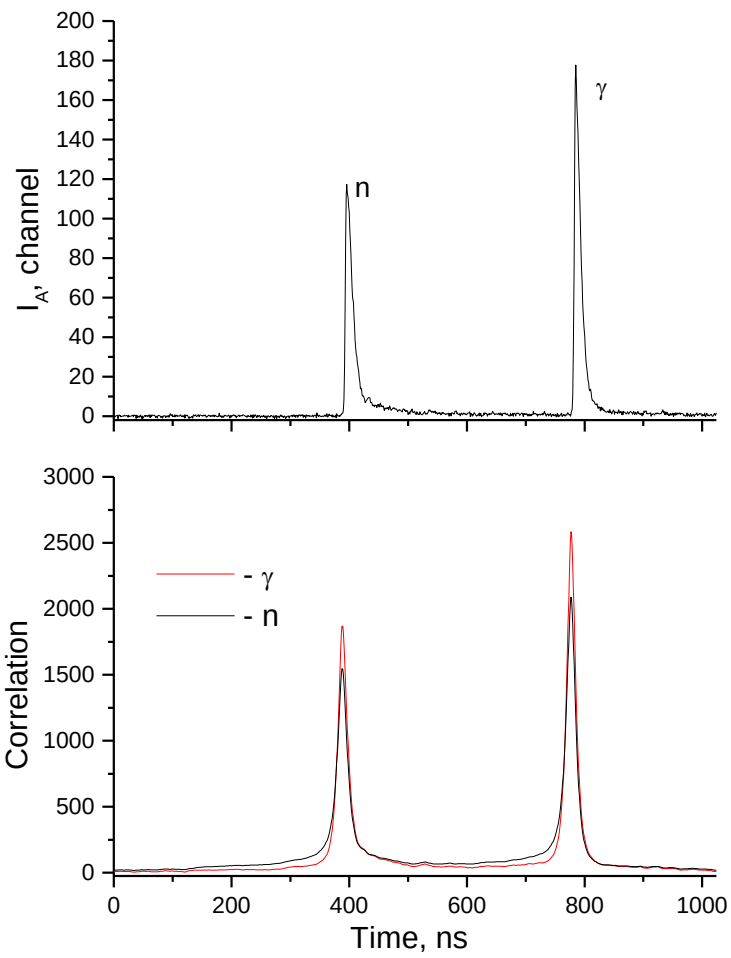


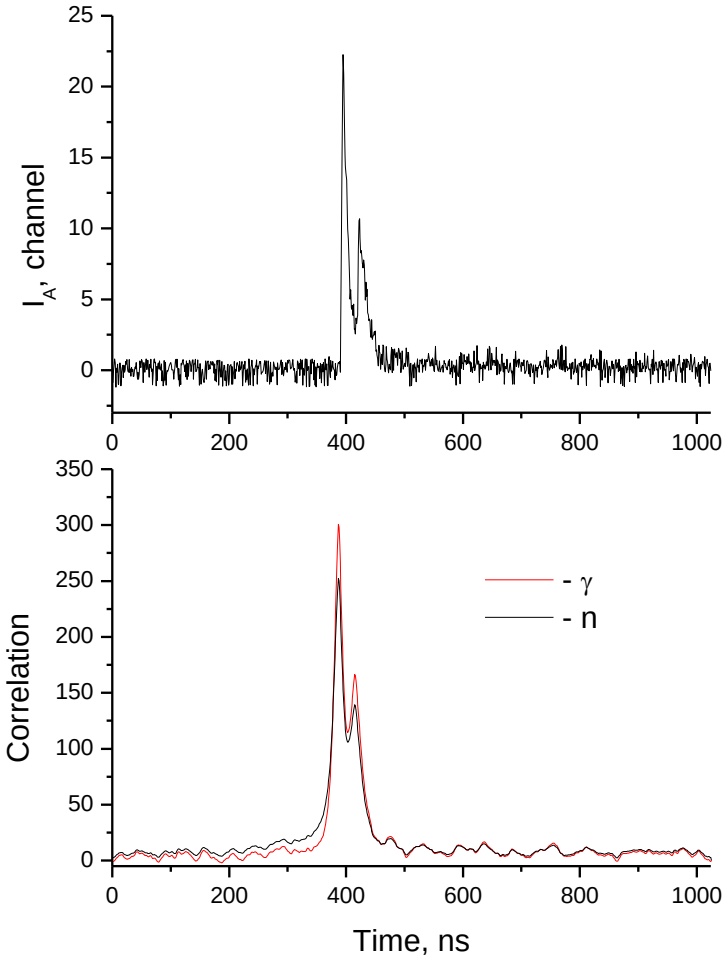
Stilbene. Pulse shape discrimination Separation and Correlation



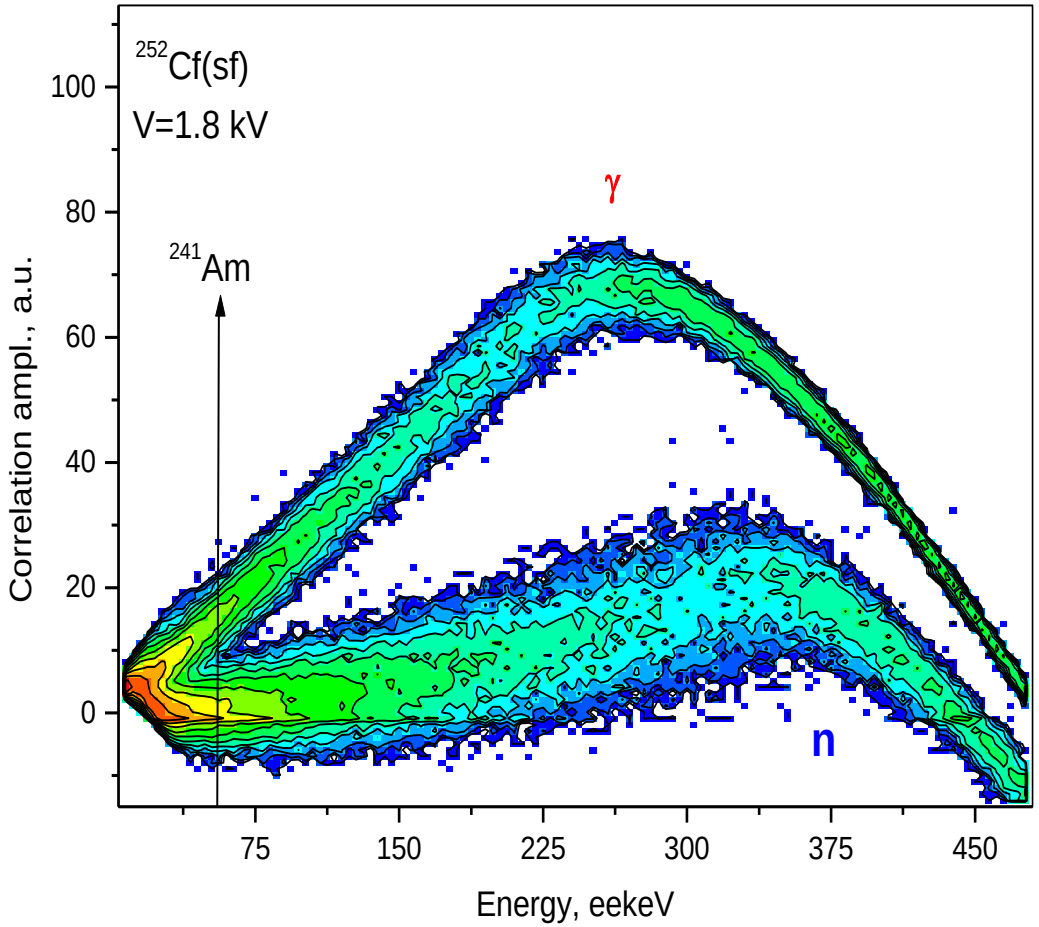


Stilbene. Pulse shape discrimination Separation and Correlation

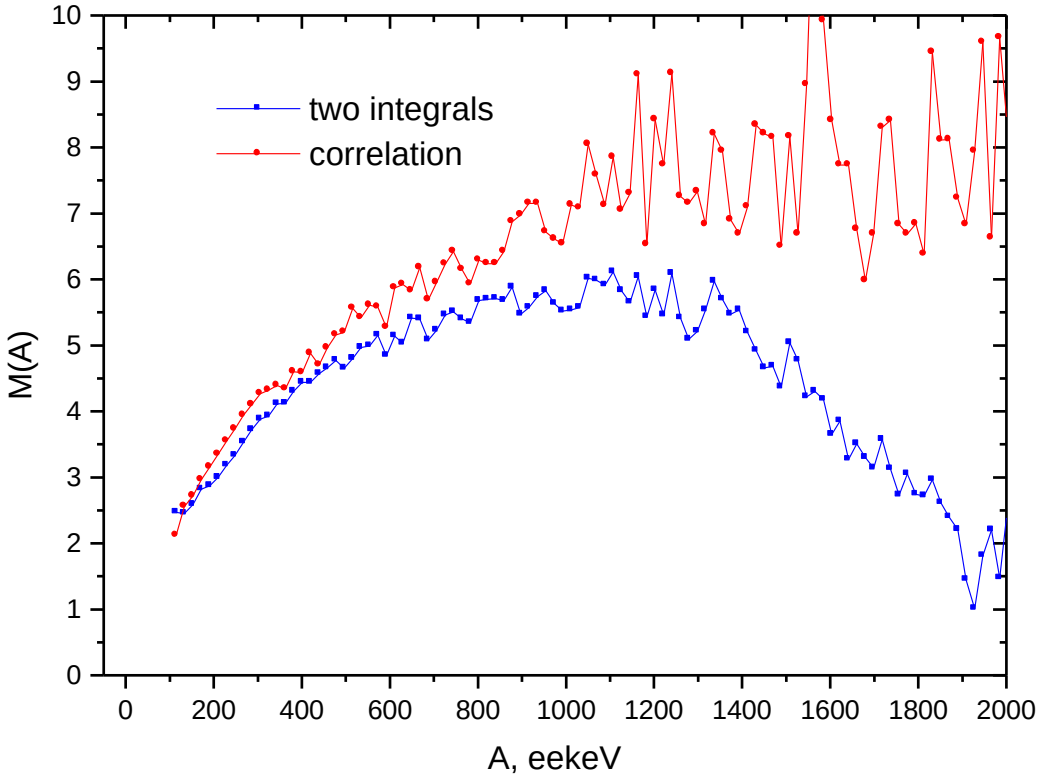




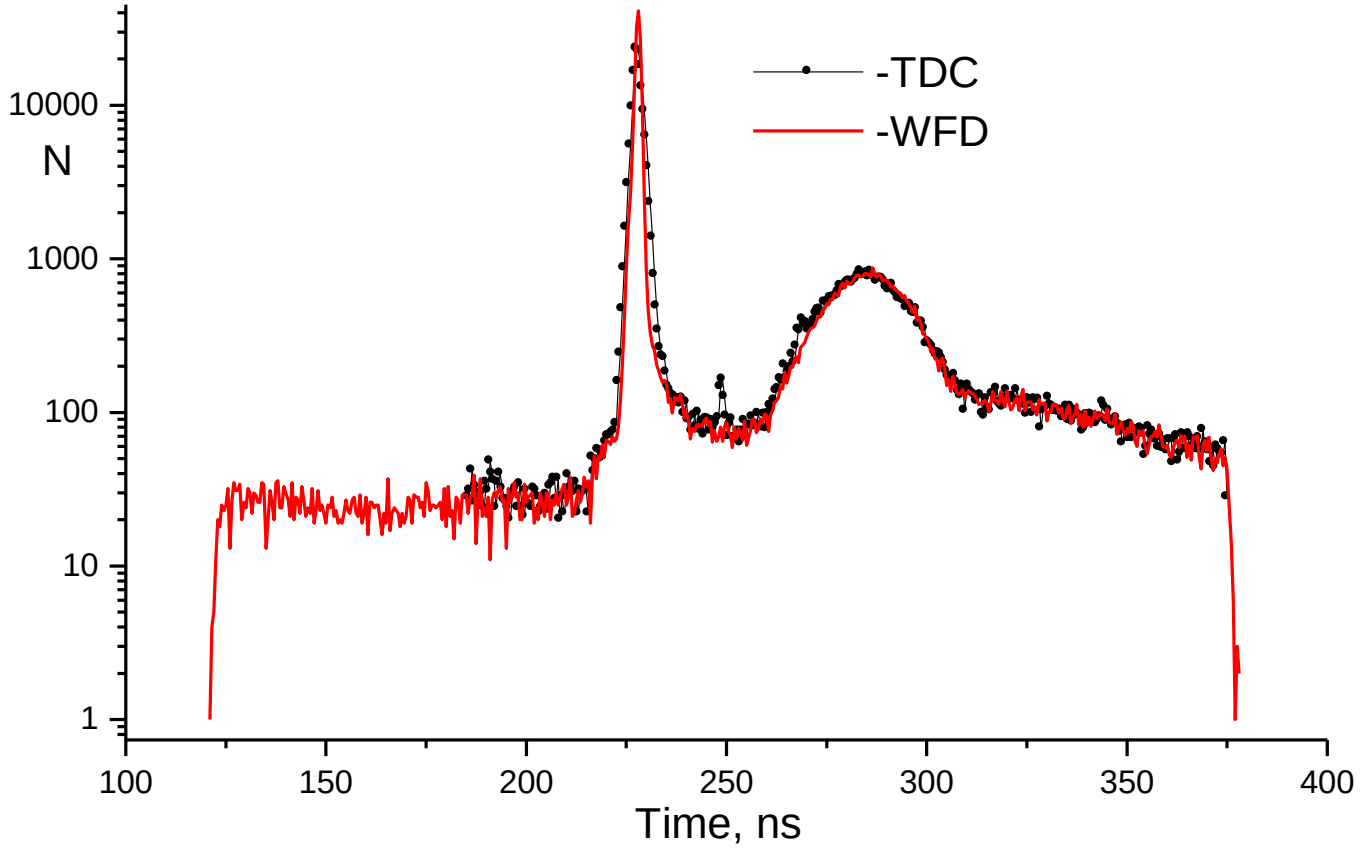
Stilbene. PS: Correlation versus total area



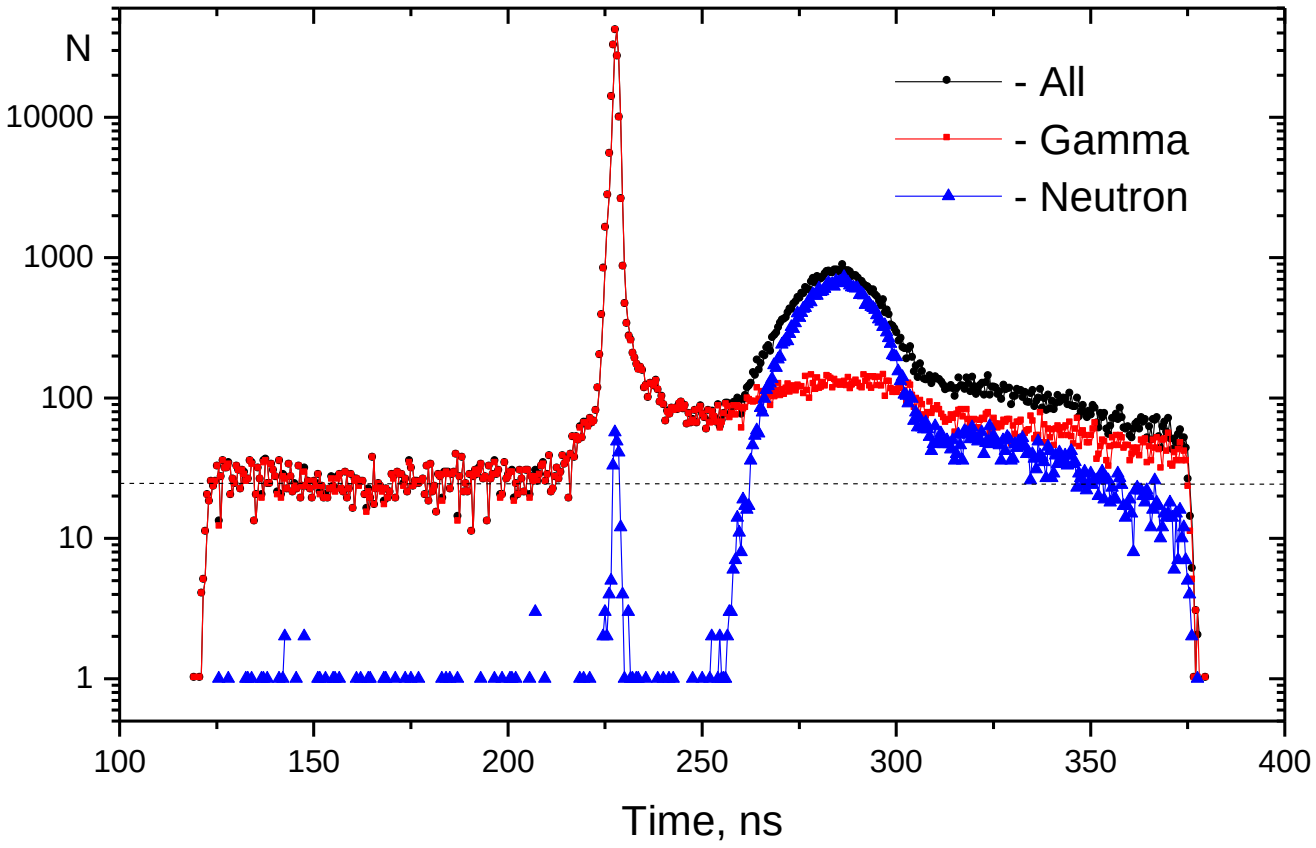
Stilbene. Double Integral Method vs Correlation method



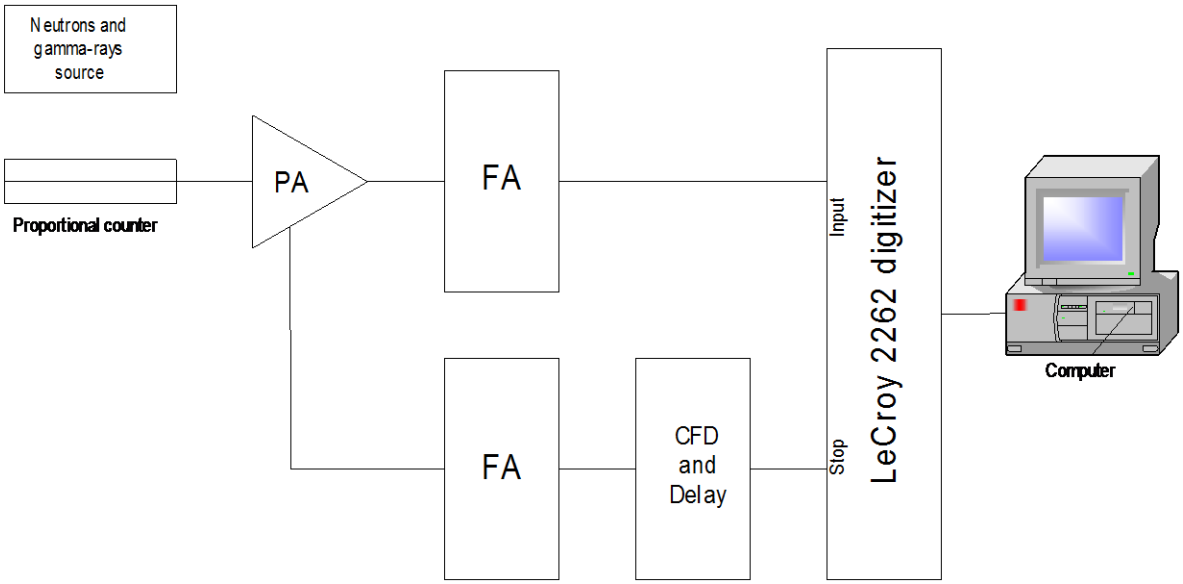
Stilbene. TOF: comparison of digitizer and conventional electronics



Stilbene. TOF with PSD

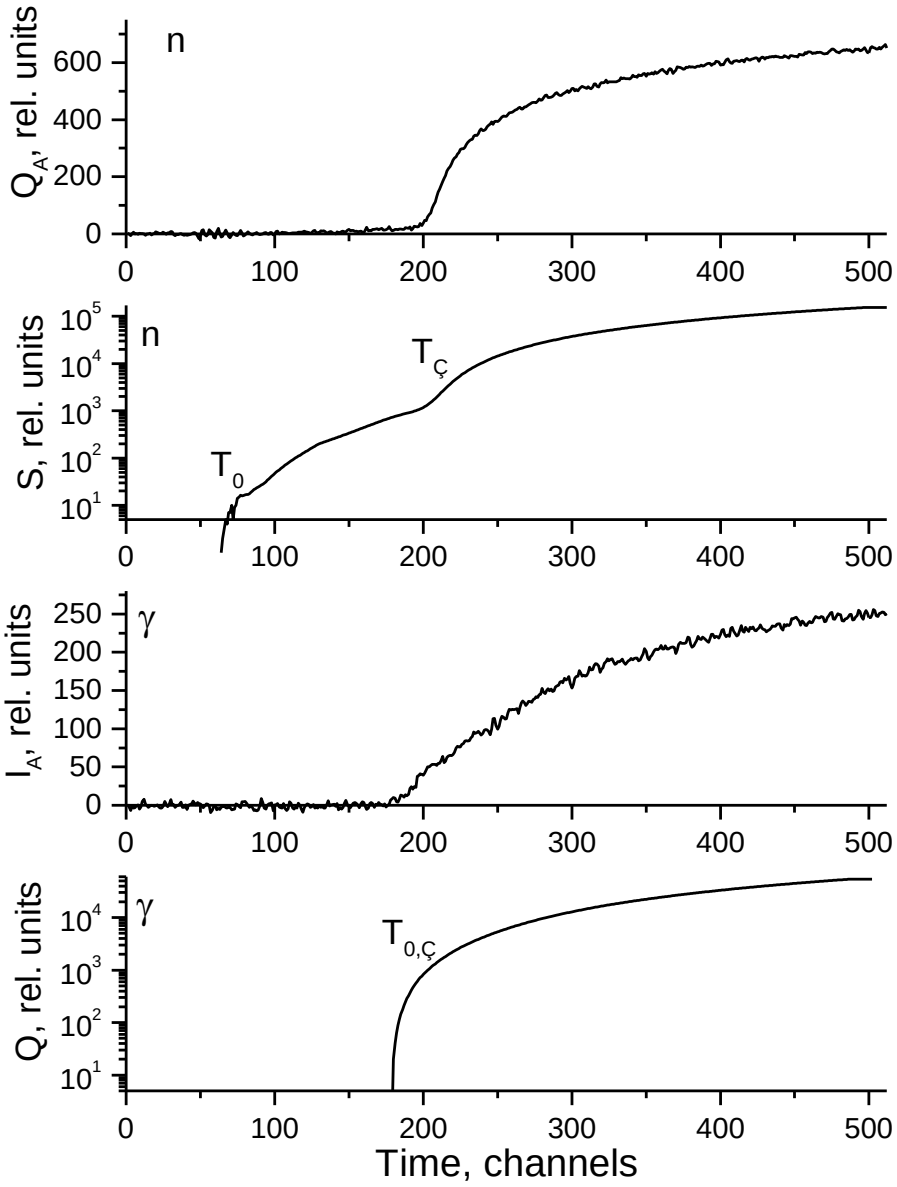


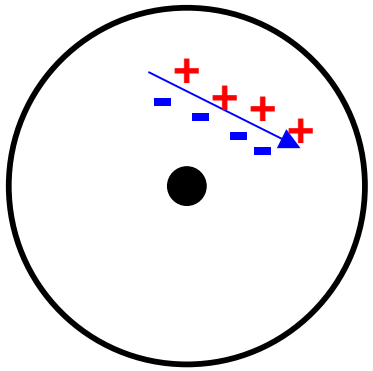
Proportional counter (PC). Block diagram of the experimental setup with a proportional counter



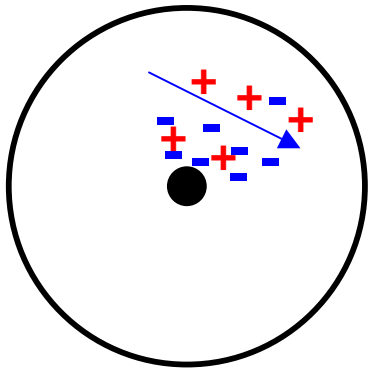
FA– fast amplifier, PA – preamplifier,
CFD – constant fraction discriminator

PC. Signals from the anode of a proportional counter





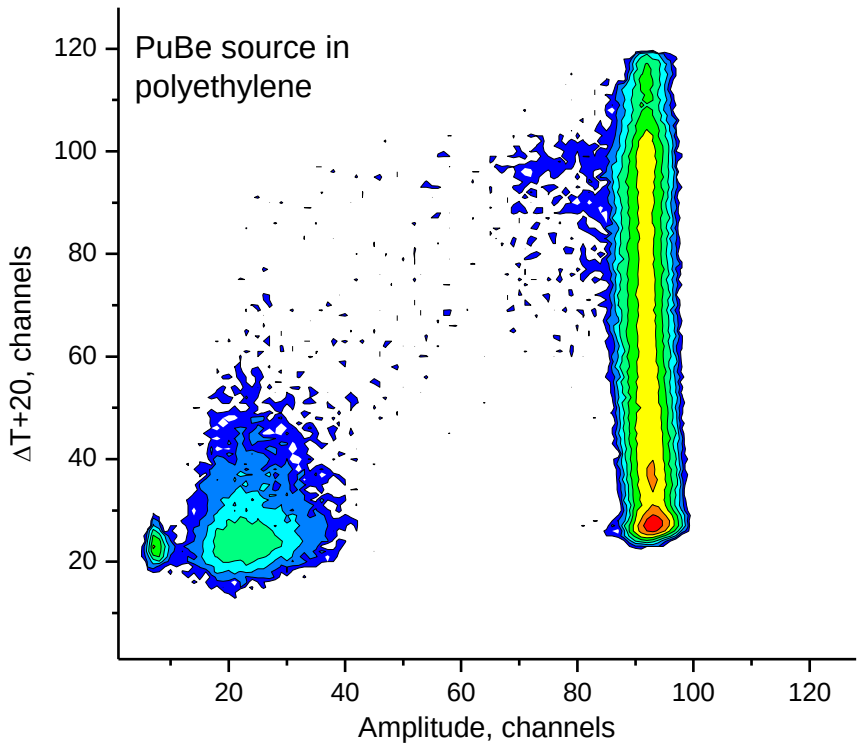
Proton



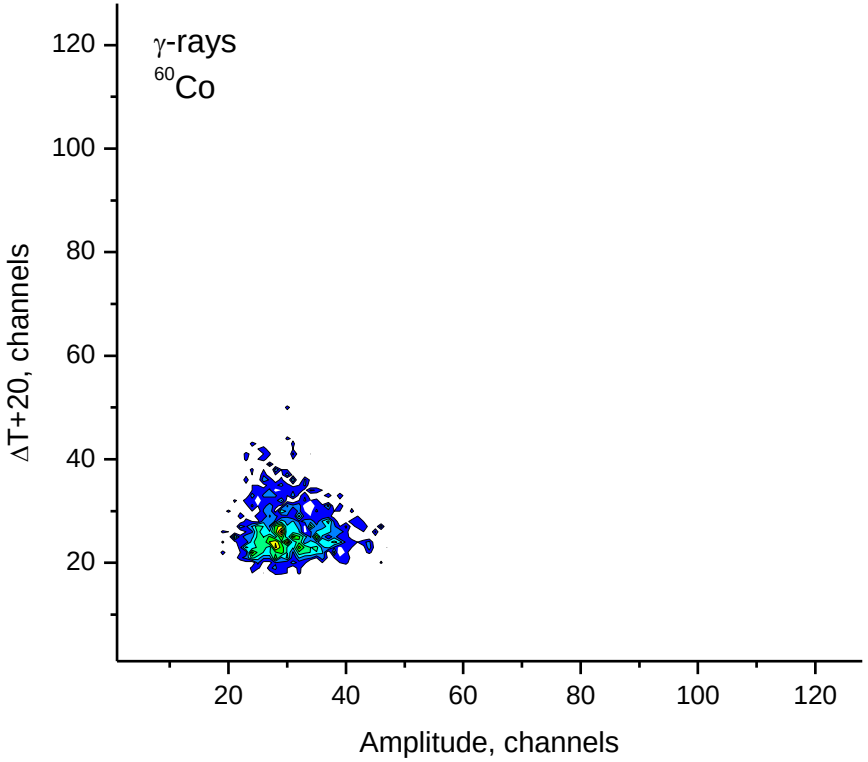
Electron

PC. Energy vs drift time

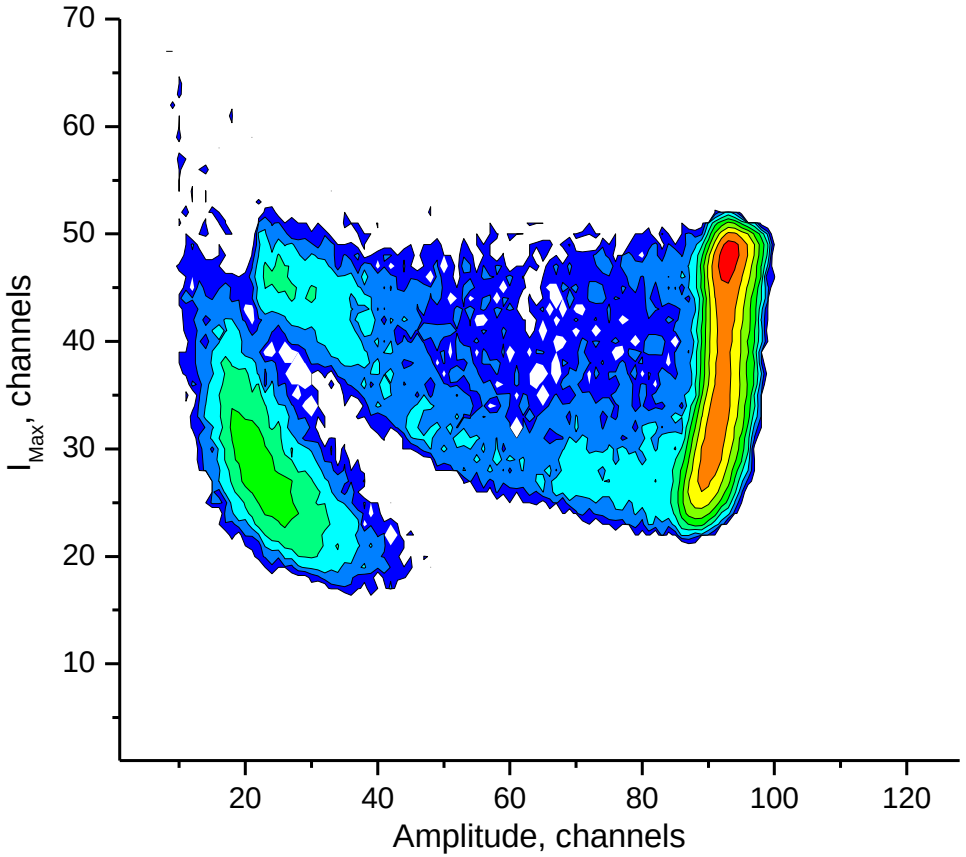
Thermal neutron + γ



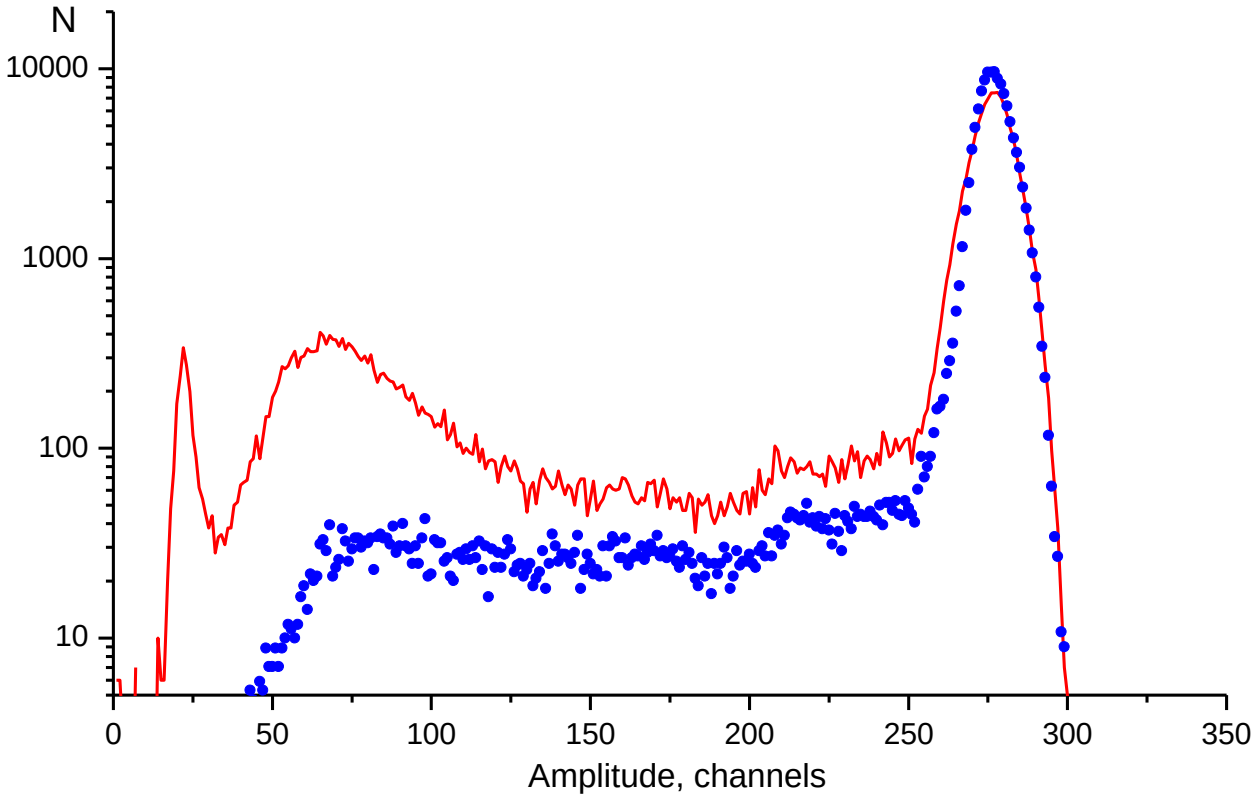
^{60}Co (γ – ray)



PC. Amplitude of the anode signal vs maximum of the current pulse

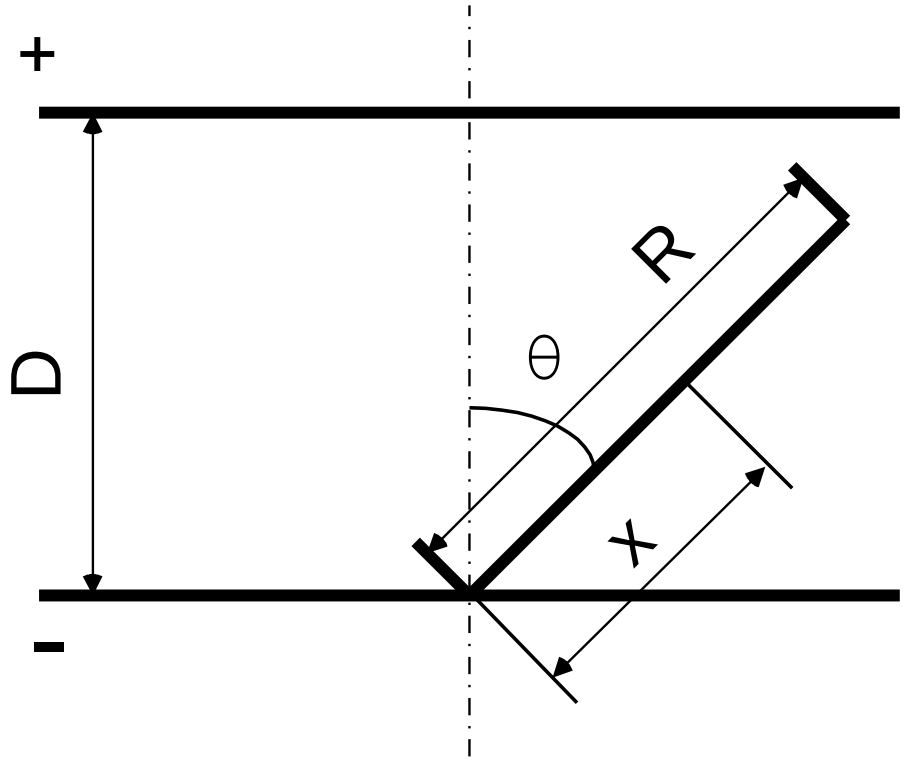


PC. The energy resolution improving



The energy resolution improved from 5.2% to 4%,
A response function became much better.

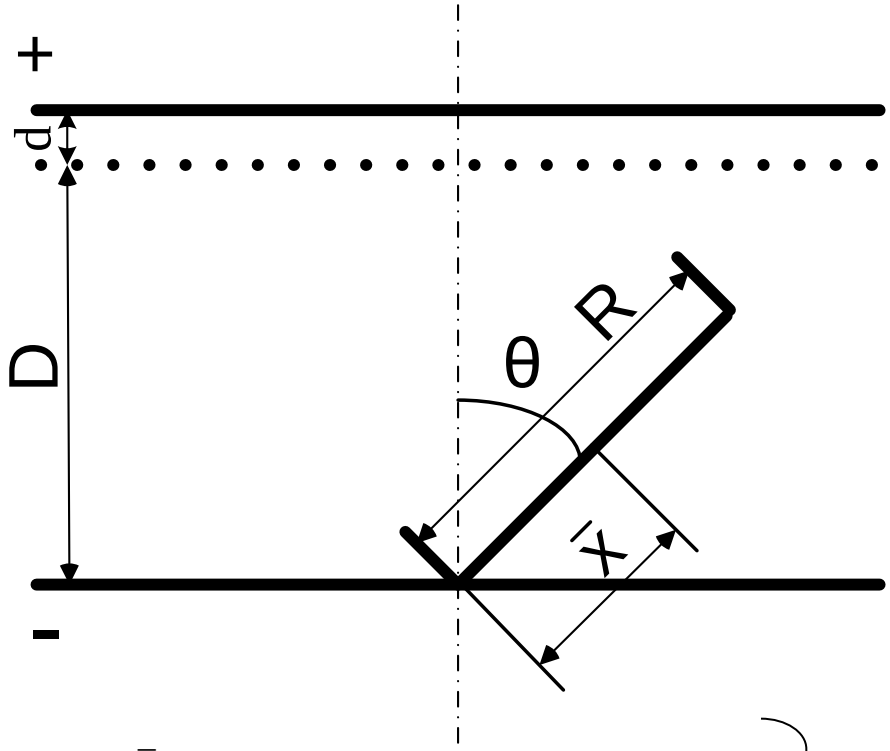
Ionisation chamber



$$Q^{-}_{An} = -Q^{-}_{Cth} = -n_0 e * \left(1 - \frac{\overline{X}}{D}\cos(\Theta)\right)$$

$$\overline{X} = \frac{1}{n_0}\int_0^R x * \rho(x)dx$$

Ionisation chamber with Frisch grid



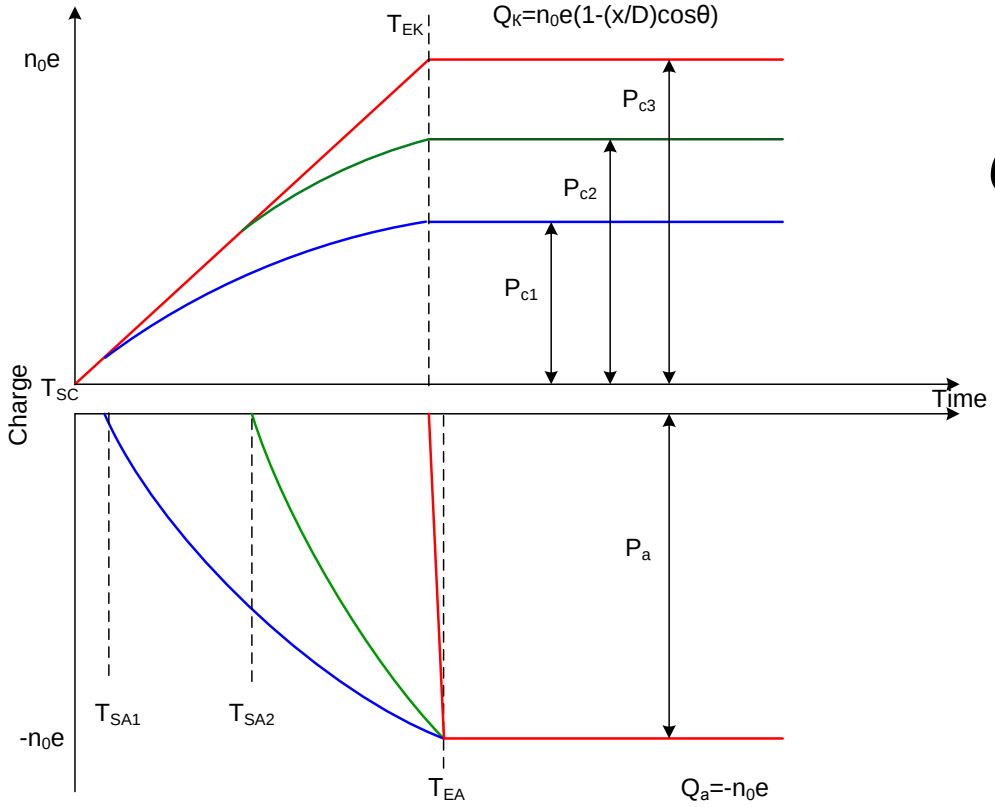
$$Q^{-}_{An} = -n_0 e$$

$$Q^{-}_{Cat} = n_0 e * \left(1 - \frac{\overline{X}}{D} * \cos(\Theta)\right)$$

$$\overline{X} = \frac{1}{n_0} \int_0^R x * \rho(x) dx$$

E, cos(Θ)

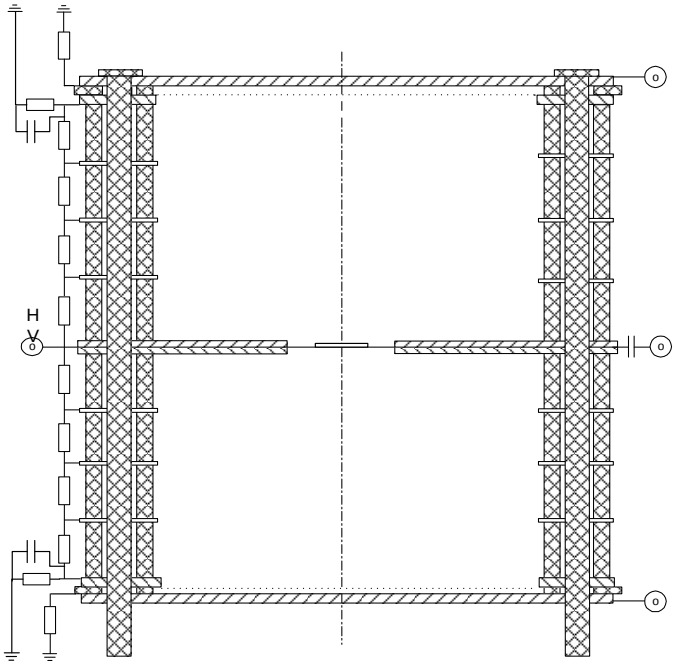
Pulse shape for IC with Frisch grid

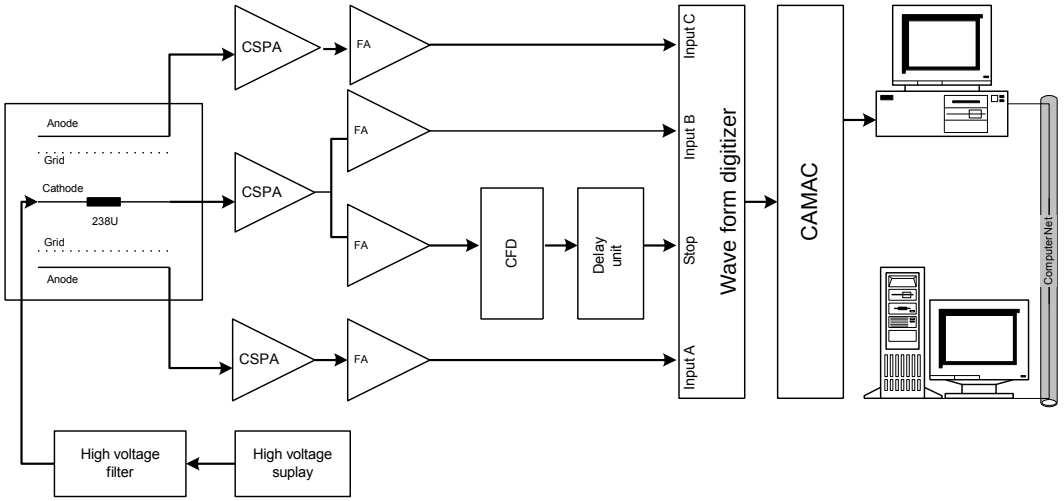


$$\bar{Q}_{Cat} = n_0 e * \left(1 - \frac{\bar{X}}{D} * \cos(\Theta)\right)$$

$$\bar{Q}_{An} = -n_0 e$$

Fission fragments spectrometer.



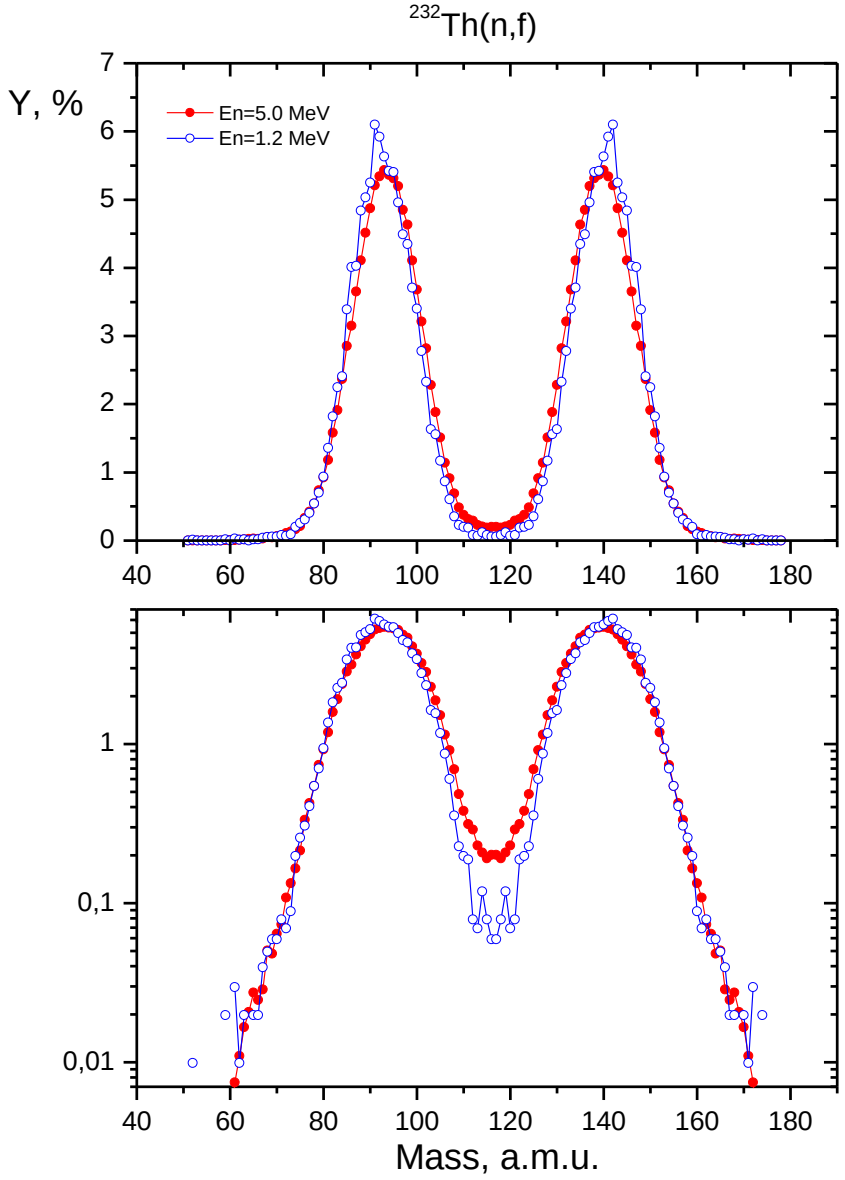


Ionization chamber: d=120 mm, height – 90 mm.
Working gas: Ar+10%CH4, Pressure – 0.75 atm.
Digitizer: LeCroy 2262, 40 MHz, Time scale – 7 μs.
^{238}U sample sizes: Diameter - 60 mm. Thickness 250 μg/cm^2.
Energy resolution 40 keV for 6 MeV α-particles.
Angular resolution - 0.065 (in cos(θ) unit).
Mass resolution ~1 a.m.u.

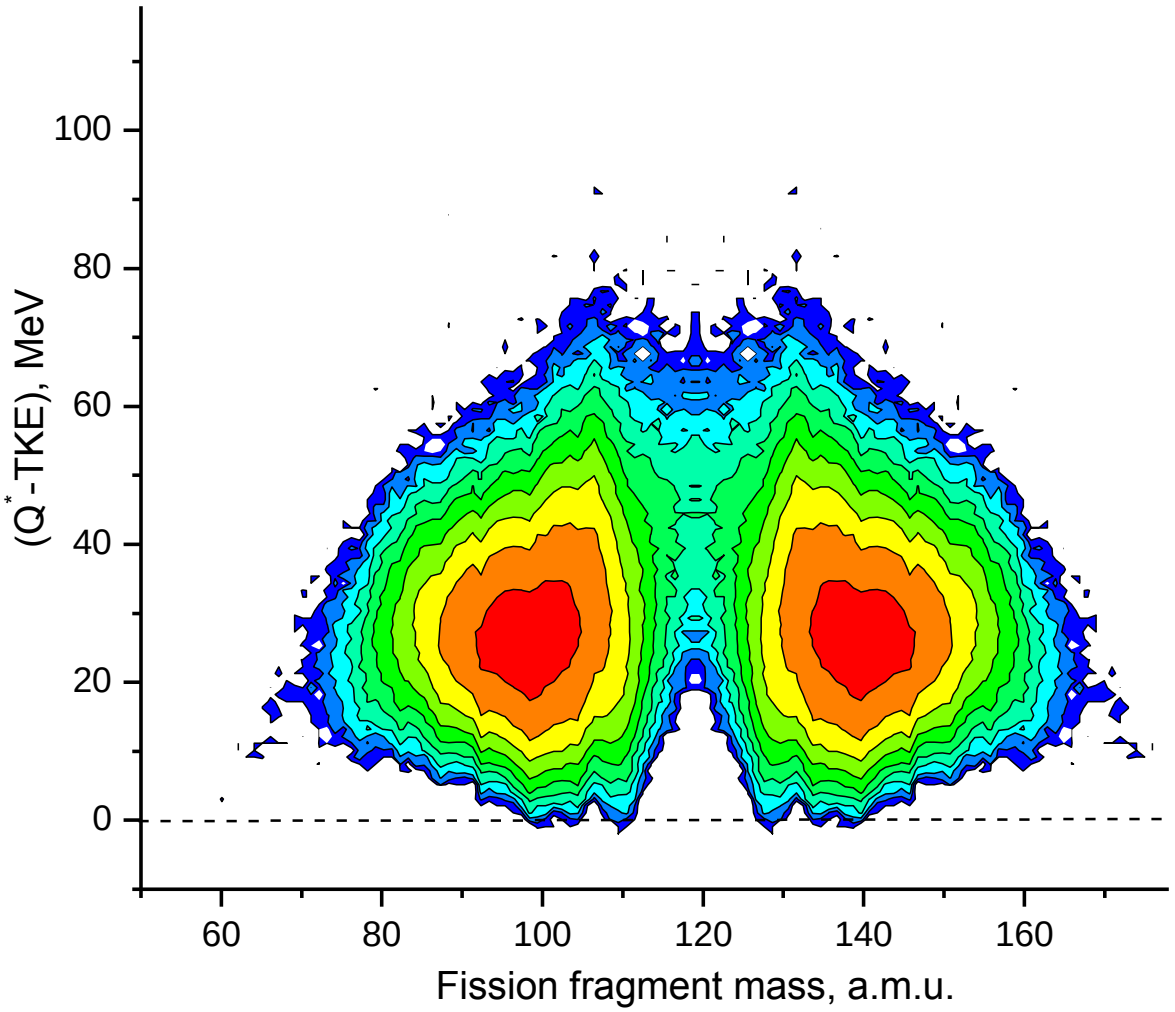
Fission fragment spectrometer properties

- Energy of both fragments
- Mass of both fragments (2E method)
- Emission angles of both fragments
- Bragg curve for both fragments
- Control of pile up
- On line measurement of electron drift velocity (working gas property on line control)
- Energy losses in the target correction
- Direct Frisch grid inefficiency measurement

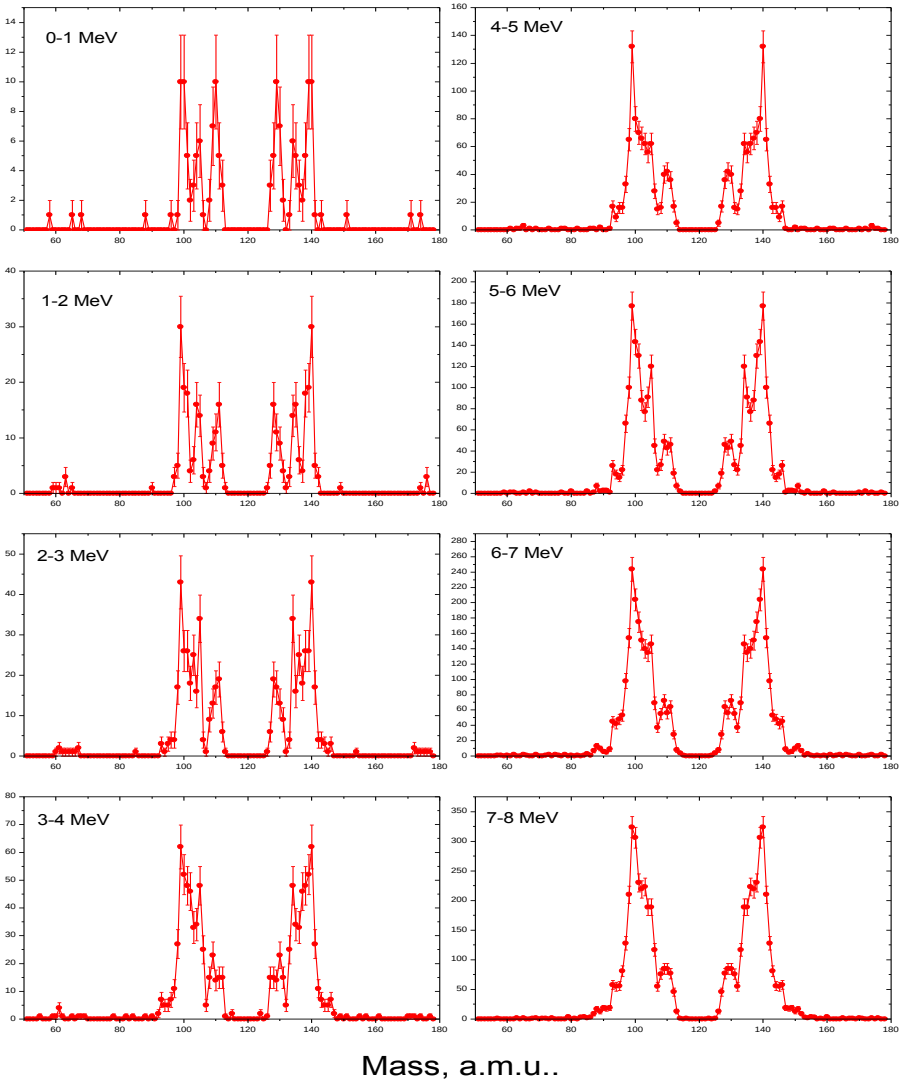
^{232}Th(n,f), En=1,2 and 5 MeV

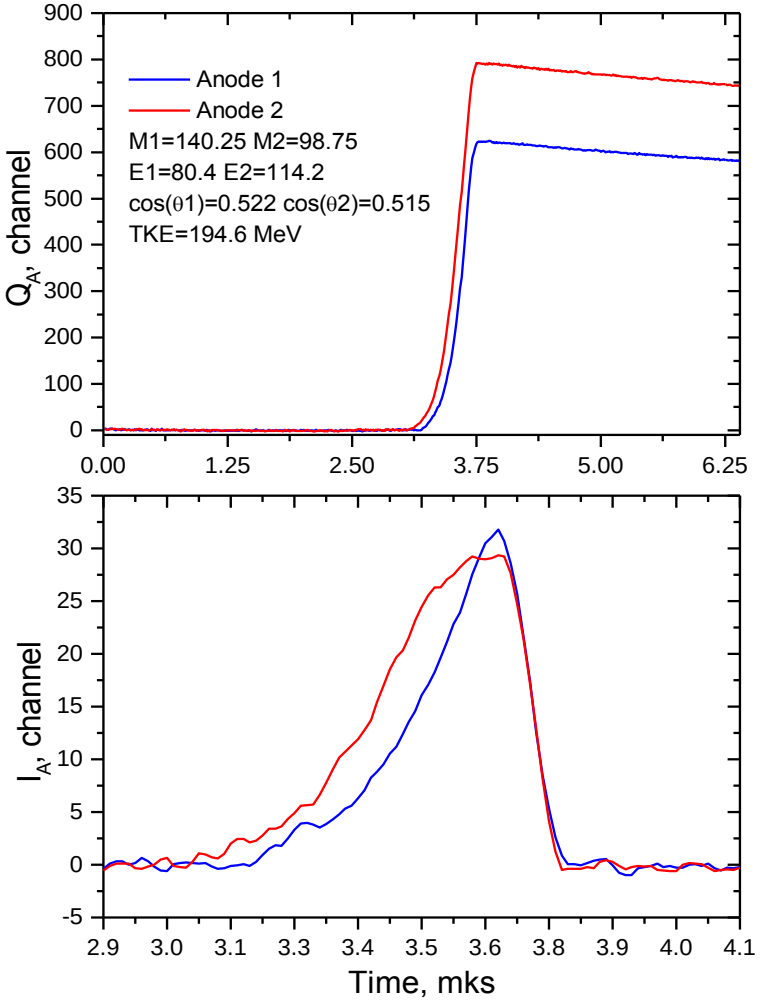


^{238}U(n,f), En=5 MeV

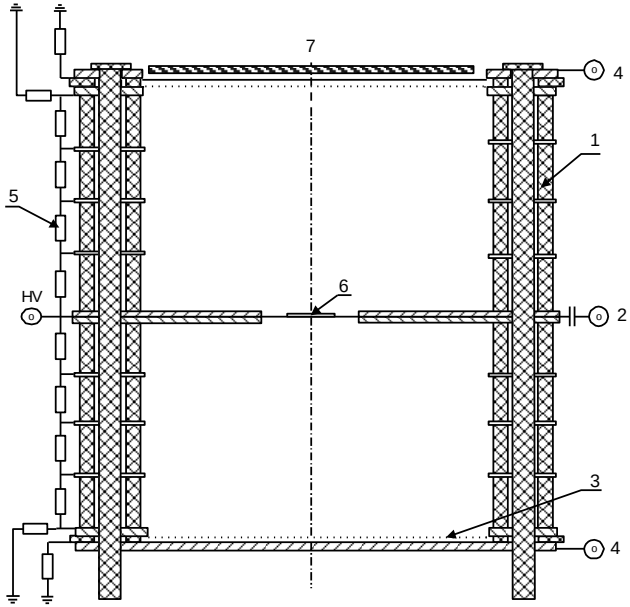


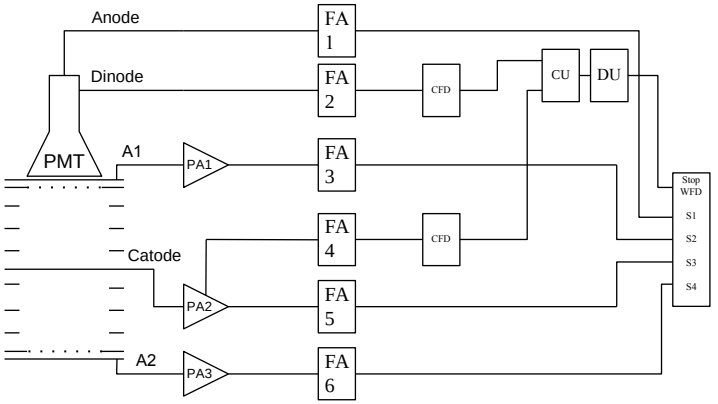
^{238}U(n,f), En=5 MeV. Cold fission.

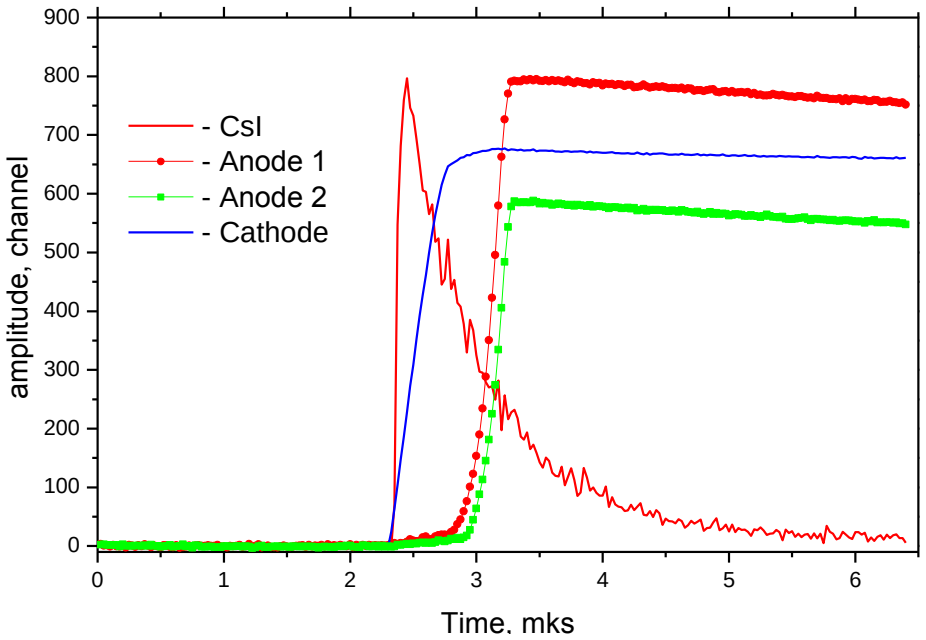


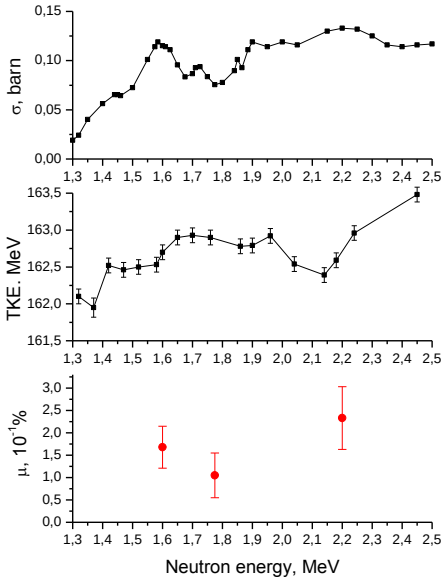


Measurement of probability of ternary fission of ^{232}Th and ^{238}U by fast neutrons

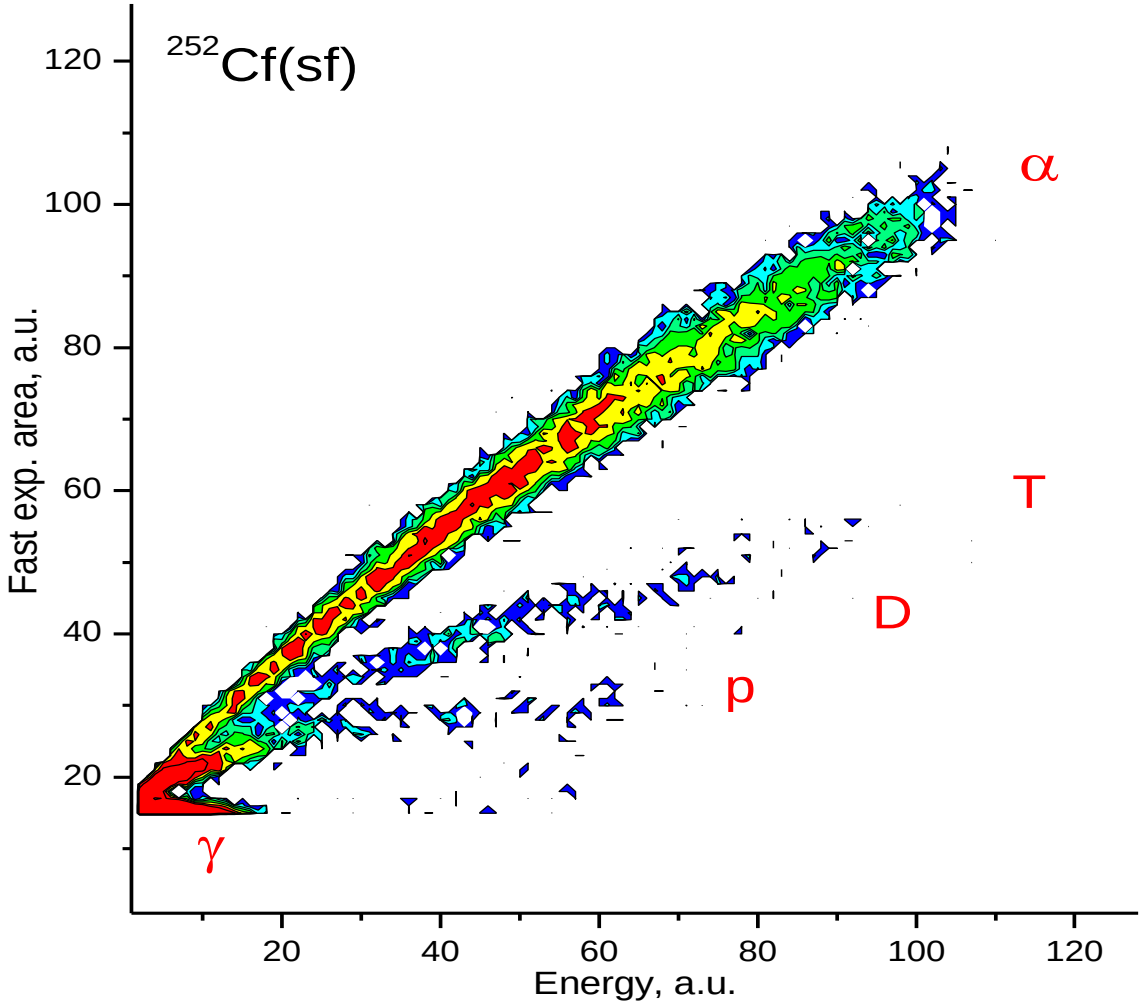








Measurement of probability of spontaneous ternary fission of ^{252}Cf



Conclusions

- Now digital signal processing for particle registration can work.
- This method allows us to perform the same operation as the analog unit does.
- We can make more complicated evaluation of digital signals and extract additional information.
- We can reach better stability and resettability of obtaining results.
- Promising results for different types of detectors were obtained.