Development and validation of an innovative industrial digital system with software for the acquisition and processing of signals from nuclear radiation detectors

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Overview

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Project goalsand aims

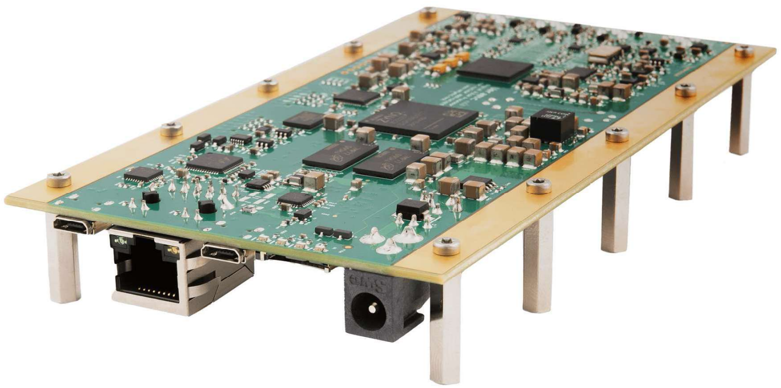
Development of a neutron and gamma radiation dosimetry system with gamma radiation spectrometry based on the following assumptions:

- No analog shaping circuits - full pulse shape information retained.
- Real-time pulse processing with minimal dead time.
- Signal processing algorithms for virtually any type of scintillation detector. Possibility to implement new algorithms.
- Development of a hardware platform enabling stable operation of the detector and acquisition system in a wide range of the number of events observed in the detector (cps).

Digital Pulse Processor - Digitizer

Digital Pulse Processor, DPP

- Full acquisition and digital processing of signals from nuclear radiation detectors and direct acquisition of signals preserving the shape of the processed pulse for further analysis.
- Real-time digital signal processing with minimal dead time for a large number of observed events (high cps).
- Processing of energy spectra directly in the device via the SoC system integrating an FPGA system and a multi-core ARM processor with the Linux operating system.



Digitizer main board.

Digital Pulse Processor Hardware

Electrical parameters:

- Two independent analog inputs: 1Vpp, 50 Ohm.
- Analog to digital converter: 500Mhz@12bit.
- Programmable input signal baseline level.
- Two CMOS standard logic inputs (measurement trigger, spectrum gating.

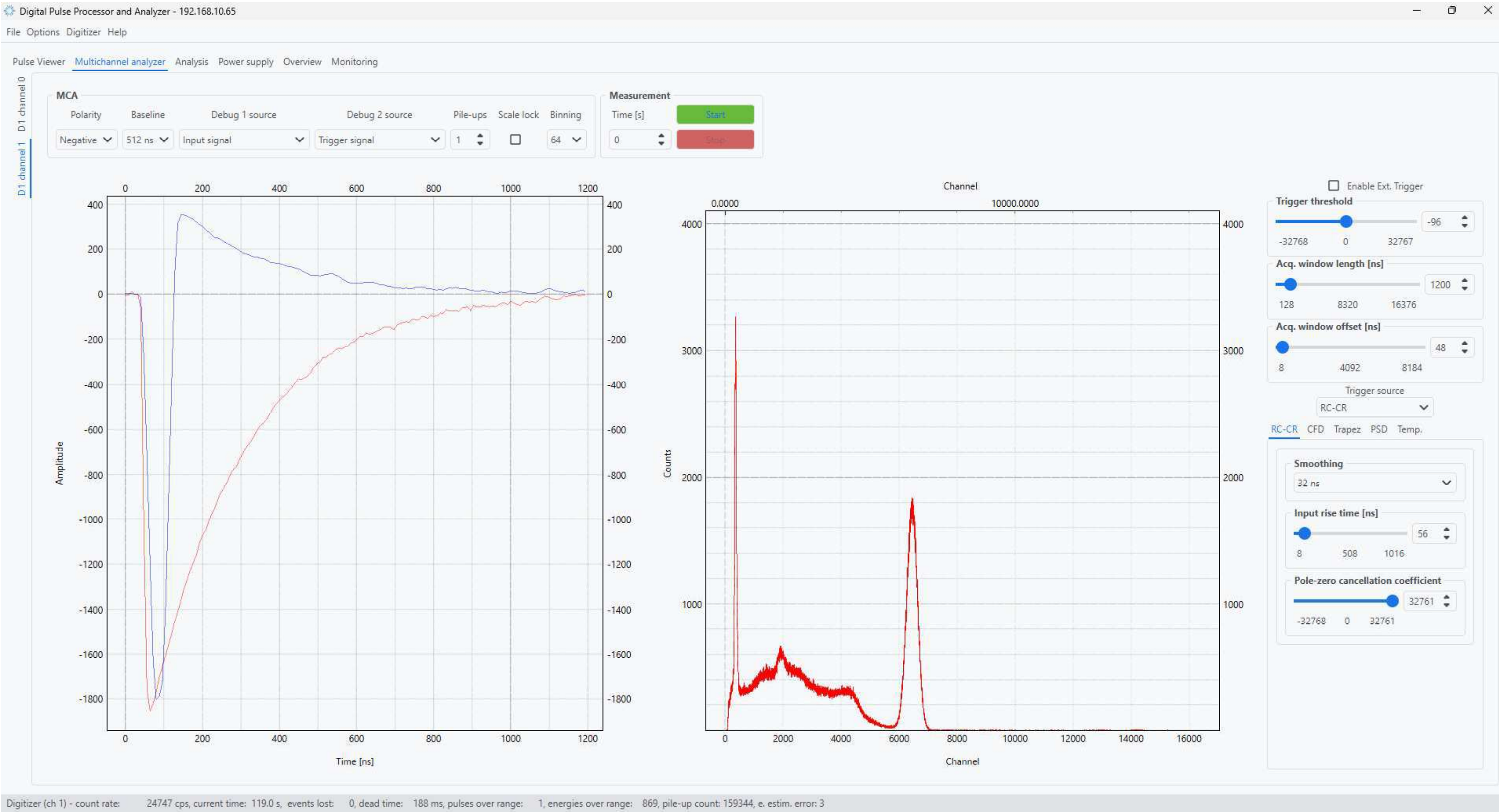
DSP platform communication:

- Hardware platform based on an integrated SoC system: FPGA + dual-core ARM A9 CPU.
- Shared memory between CPU and FPGA: 1Gb DDR3.
- Communication interfaces: 1Gb Ethernet, USB 2.0 ULPI (the device presents itself as a network card when connected to a PC).

Digital Signal Processing, DSP

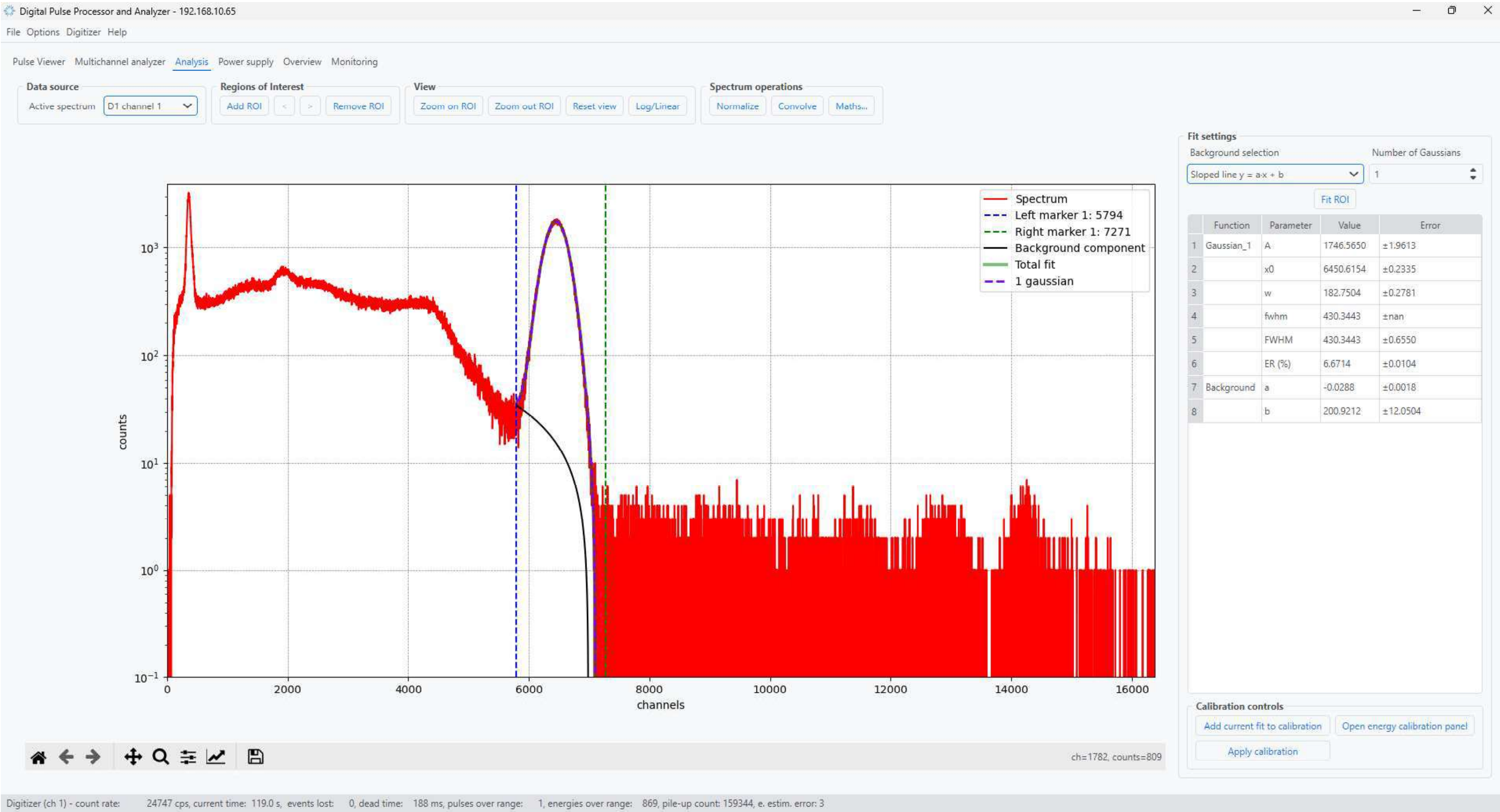
- Pulse detection methods: threshold detector, RC-(CR)2, and RC-CR with pole-zero cancellation.
- Detection of pile-up phenomena for any type of pulse detection algorithm with dynamic expansion of the acquisition window.
- Baseline estimation.
- Trapezoidal filtering with pulse energy estimation.
- Pulse energy estimation based on integration of signal samples.
- Constant fraction discriminator CFD.
- Neutron/gamma pulse shape discrimination PSD based on pulse shape: charge comparison, zero crossing.
- List mode with extended functionality (e.g. timestamp, logical markers, pulse energy, estimates of selected signal parameters).
- View test signals for each method.
- Extensive measurement statistics system.

Digitizer software



Digitizer software - multichannel analyser window.

Digitizer software



Digitizer software - multichannel analyser window.

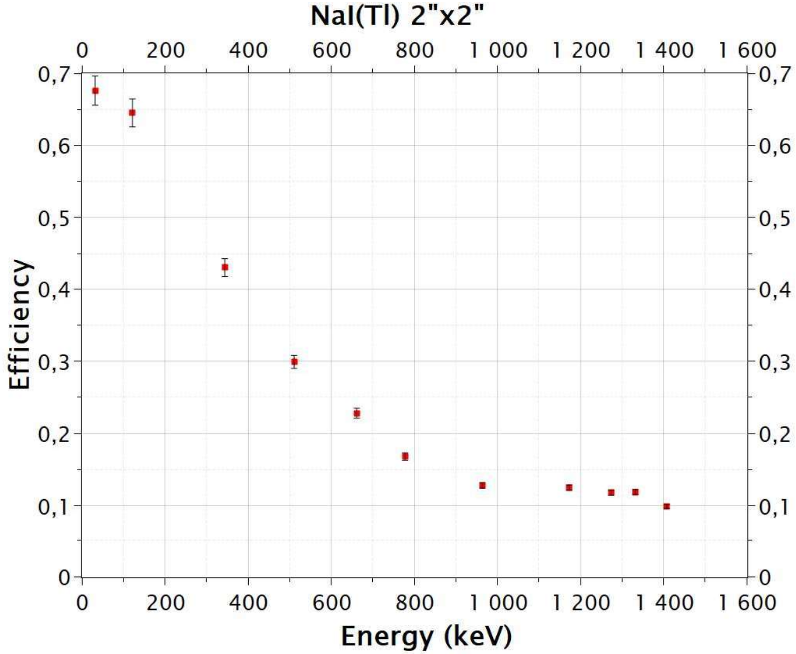
Digital Pulse Processor in dosimetry

- Dynamic compensation for the impact of digitizer temperature changes.
- Dynamic compensation of the photomultiplier supply voltage due to changes in the scintillator and photomultiplier temperature.
- The system performs every step necessary for correct spectrometry and dosimetry of neutron and gamma radiation, regardless of the photodetector and scintillator used (PMT or SiPM) (!)
- No saturation of the signal processing path efficiency was observed in the measurements performed - the detector switched to the current mode earlier (!)

Gamma Ray Probe - NaI(Tl)

- Scyntylator NaI(Tl) 2" x 2" + Hamamatsu R6231 PMT.
- Active photomultiplier voltage divider - stable operating point regardless of the number of observed events (!)
- The number of events in the energy compensated gamma radiation spectrum is directly proportional to the gamma radiation dose.

Digitizer and two scintillation probes.

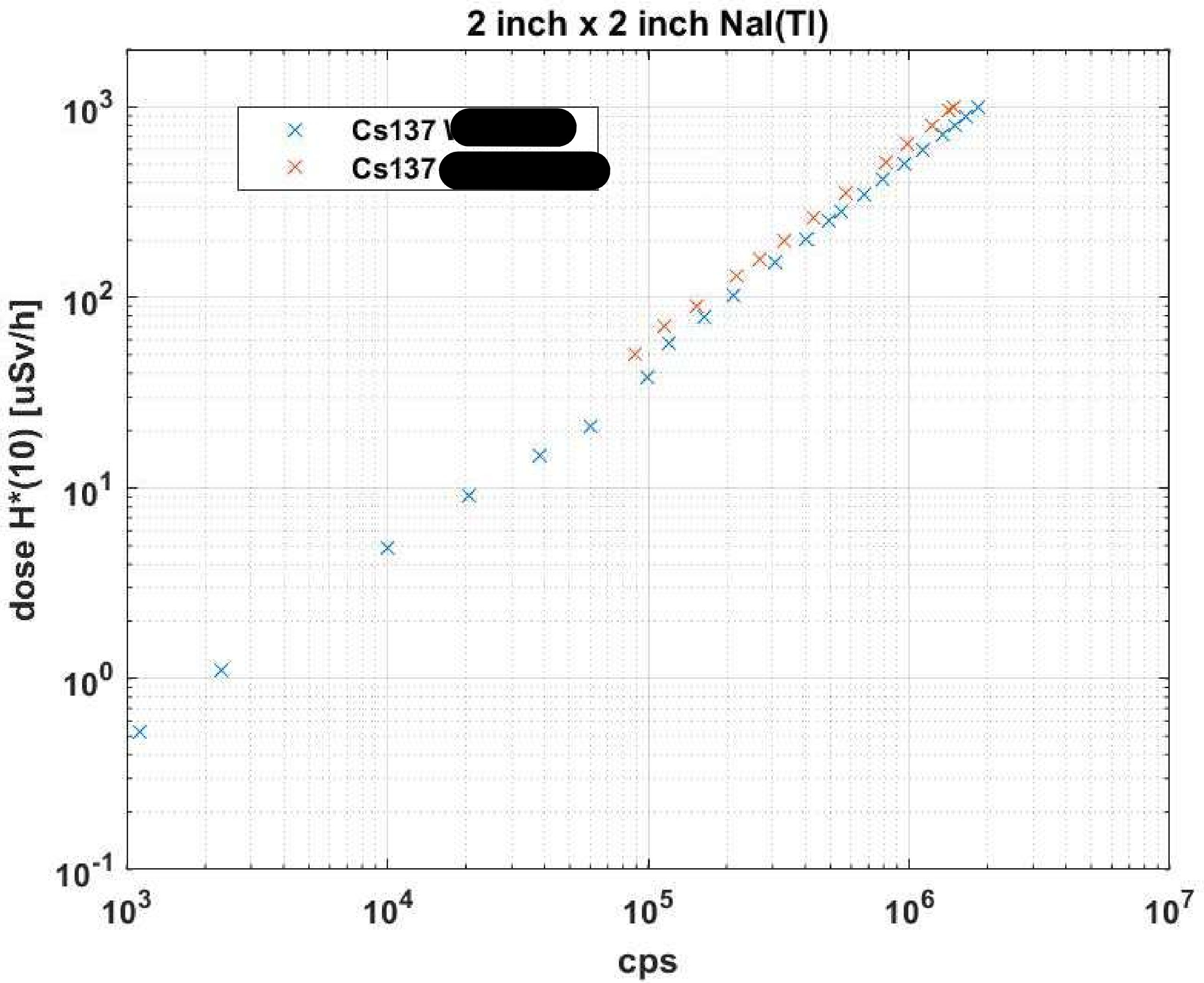


NaI(Tl) 2" x 2" scintillator full energy peaks emission quantum efficiency.

Gamma Ray Probe - NaI(Tl)

- Complete probe equipped with an active voltage divider.
- Quantum efficiency calibration performed on isotopes Cs137, Co60, Na22, Eu152.
- The measurements were performed on reference sources in an accredited laboratory - the result was 1 mSv/h (!)
- This is a range at least 4 times greater than the leading isotope identification (RIID) spectrometers available on the market.
- The limitation in increasing the dose was not the digitizer, but the current efficiency of the photomultiplier power supply.
- It is possible to further increase the measurement range by replacing the scintillator with a smaller one or with a scintillator with a shorter decay time.

Gamma Ray Probe



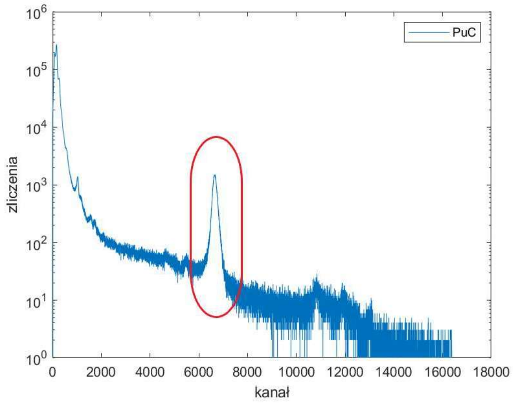
Dependence of the dose from gamma radiation on the number of counts in the detector.

Neutron/Gamma Ray Probe - CLYC

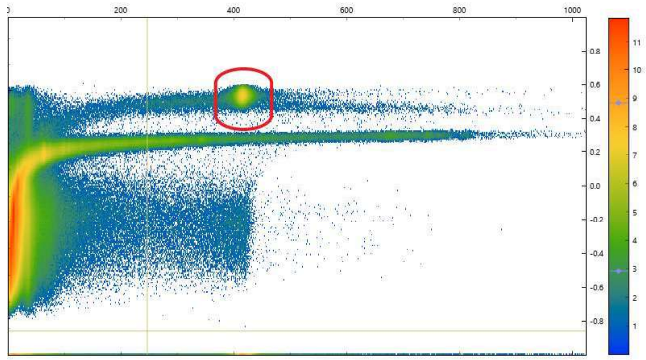
- Scyntylator CLYC 6EL 38mm x 38mm + Hamamatsu R6231 PMT.
- Active photomultiplier voltage divider.
- Scintillator with very good energy resolution of gamma radiation doped with lithium-6.
- Lithium has a large active cross section for thermal neutron capture.
- The number of events in the 3.2 MeV peak is proportional to the neutron radiation dose.
- Good energy separation between gamma and neutron radiation - energy gate may be sufficient for events near the 3.2 MeV peak.
- Possibility of using neutron/gamma radiation discrimination algorithms, which additionally improves the quality of radiation discrimination (PSD + energy gate).

Neutron/Gamma Ray Probe

- Detector with a polyethylene cube moderator.
- Good radiation discrimination.
- Possibility to detect fast neutrons due to the presence of chlorine in the scintillator material.

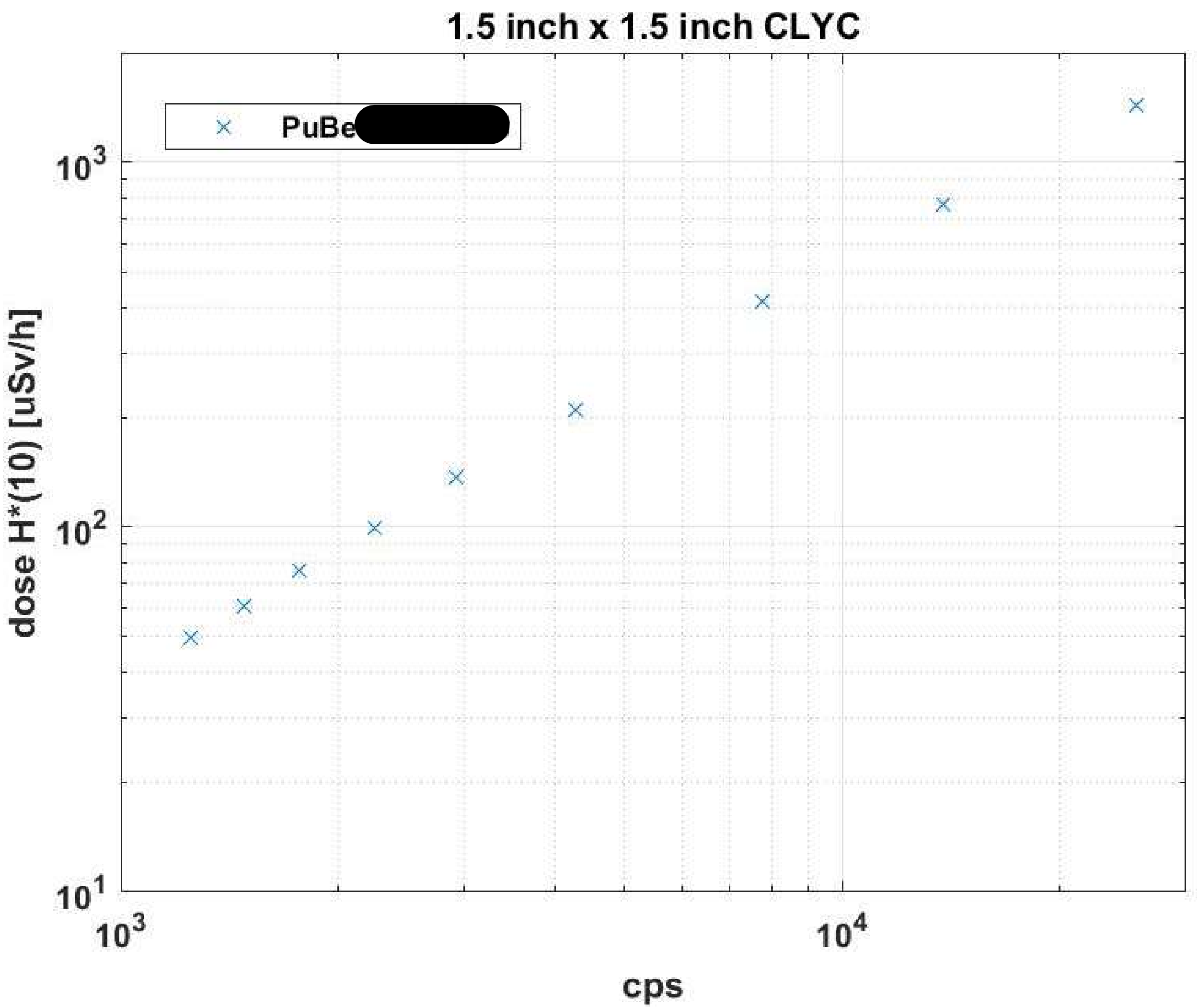


Gamma energy spectrum for the CLYC detector and the PuC source.



Neutron/gamma radiation discrimination.

Neutron/Gamma Ray Probe

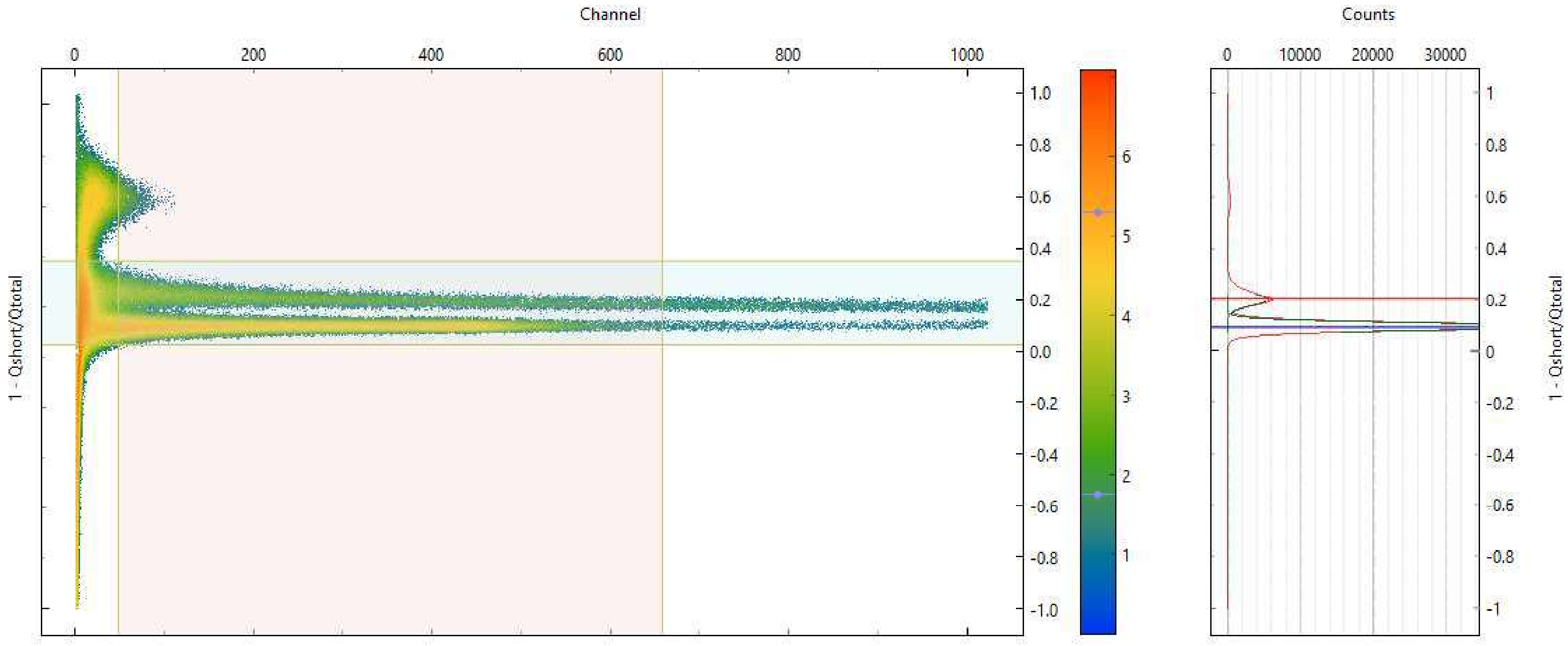


Dependence of the dose from neutron radiation on the number of counts in the detector.

Neutron/Gamma Ray Probe - EJ-276

- Organic scintillator EJ-276D 38mm x 38mm + Hamamatsu R6231 PMT.
- Active photomultiplier voltage divider.
- The scintillator enables the detection of both gamma radiation and neutron radiation in the fast neutron range – there is no need to use a radiation moderator.
- This is an organic scintillator - there is no way to directly determine the energy of radiation. Detection by the phenomenon of proton recoil.
- Problematic radiation dosimetry.

EJ-276 Pulse Shape Discrimination



Organic scintillator neutron/gamma radiation discrimination.

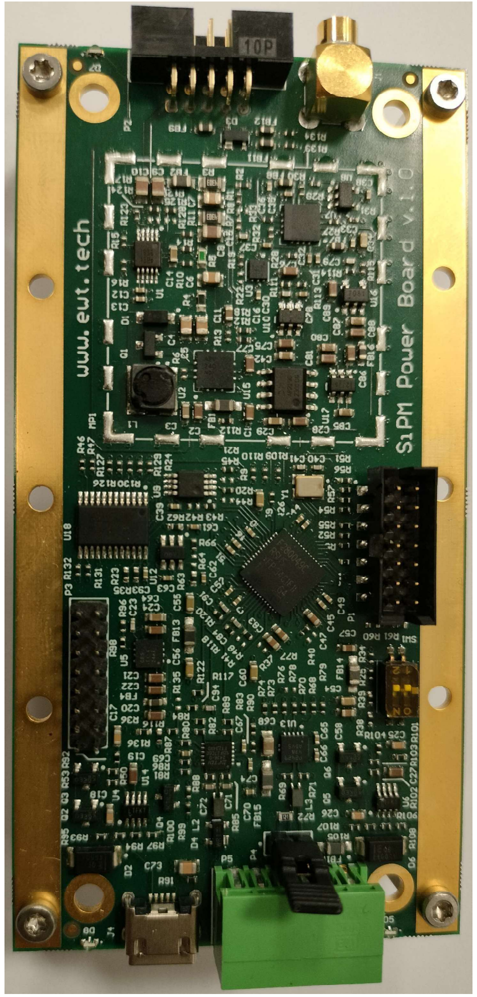
Silicon photomultiplier SiPM

- Advantages: size, no sensitivity to magnetic fields, high gain.
- Disadvantages: more noise compared to PMT, limited size of photosensitive surface, radiation damage.
- Complete detector: SiPM photomultiplier, transimpedance amplifier (TIA), temperature sensor, calibration LED.
- The TIA amplifier enables stabilization of the SiPM operating point regardless of the number of events observed in the detector and enables maintaining the signal timing parameters.

Silicon photomultiplier with GAGG scintillator and transimpedance amplifier circuit.

Power supply for silicon photomultipliers

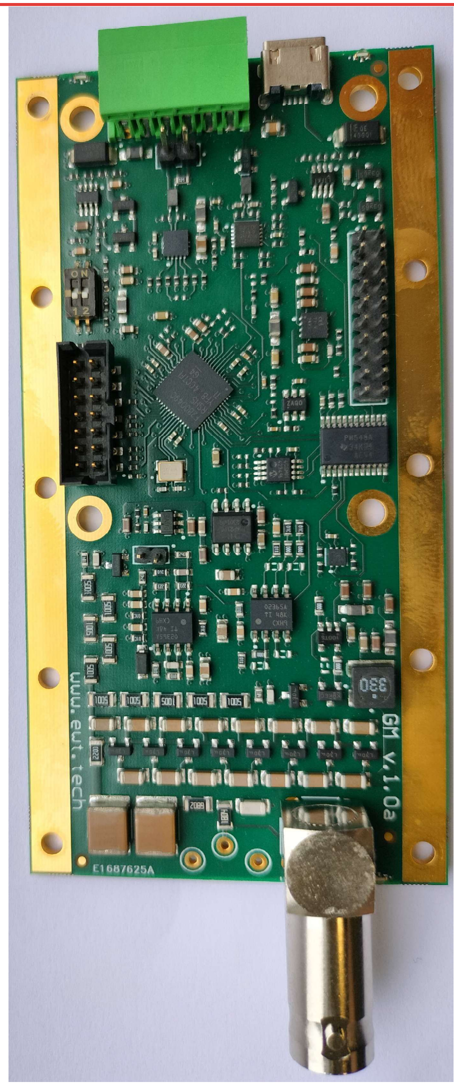
- Dimmensions: 50 mm x 100 mm.
- Communication: USB, RS-485.
  Protocol: Modbus
- Complete solution based on a real-time microcontroller.
- Output voltage: 20 V - 70 V. Output current: 5 mA.
- Functionality: SiPM temperature-compensated supply voltage compensation, LED driver, temperature measurement, power supplies for TIA amplifiers.



Power supply system dedicated to silicon photomultiplier with temperature compensation function.

GM Counter

- In the case of large doses it is necessary to use Geiger counters.
- Dimmensions: 50 mm x 100 mm.
- Communication: USB, RS-485. Protocol: Modbus
- Complete solution based on a real-time microcontroller.
- Simple integration with industrial solutions.



GM Counter board

Application example of using GM counter modules