Building a nuclear physics lab in the 21st century

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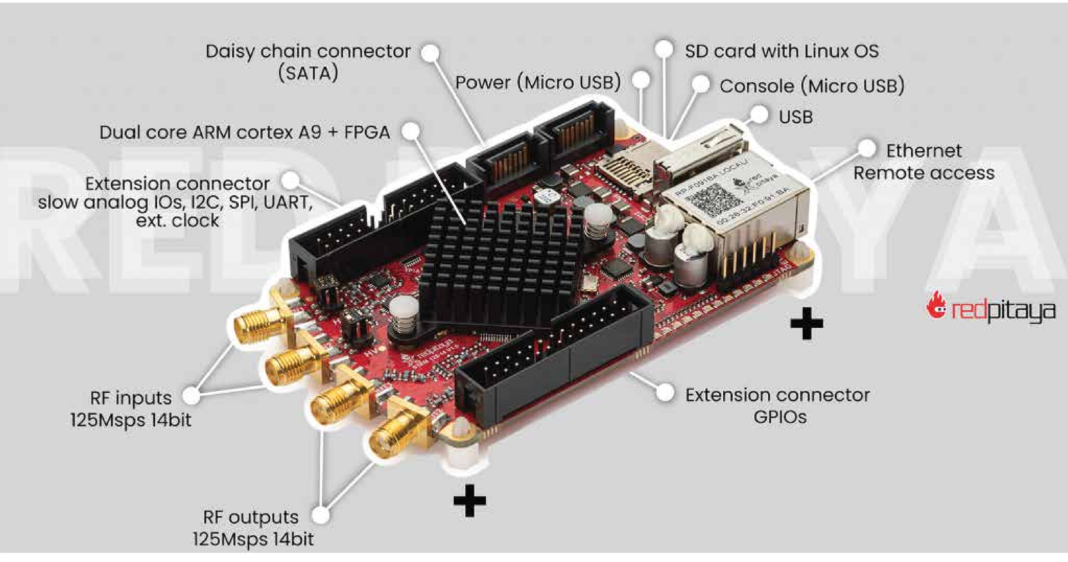
1 Hardware & Software

Implementation of an **innovative system** for **reading** and **processing data produced by particle detectors**, based on a single-board computer, the Red Pitaya **STEMlab 125-14 [1]**.



(picture from [1])

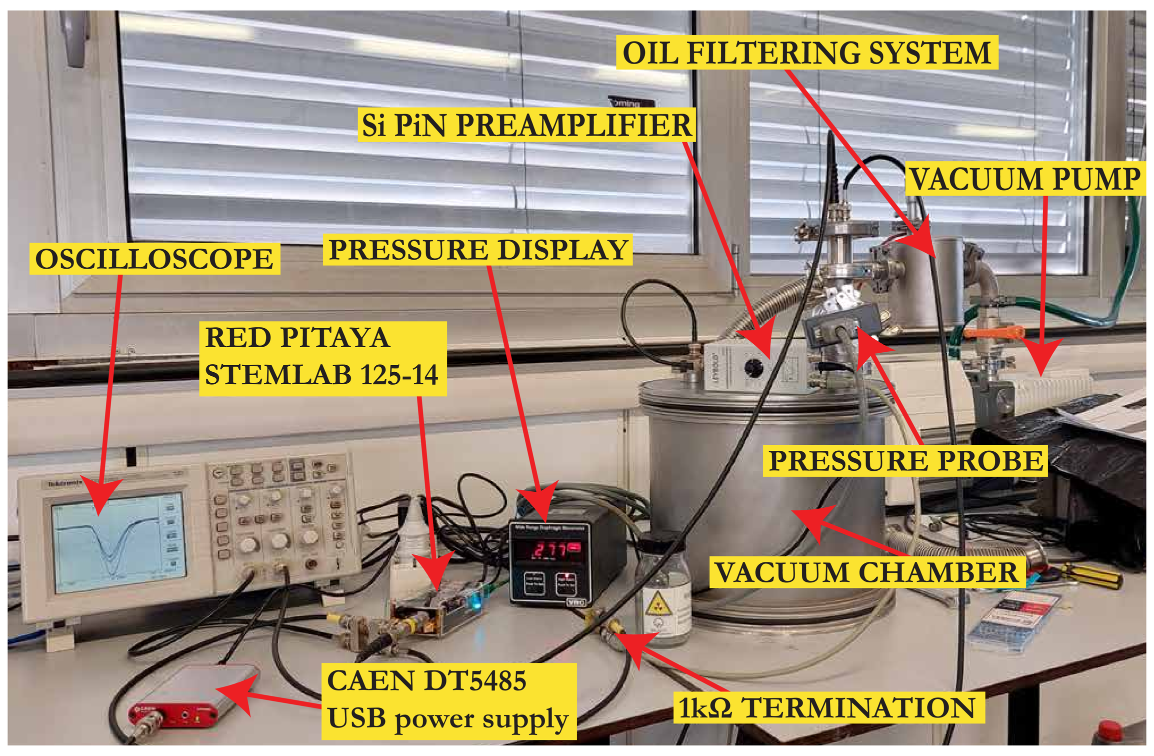
Main features:
- **Compact size** (credit card)
- Integrate a **CPU** with Linux-based OS and a **FPGA**
- Two **fast inputs** and two fast outputs (**14 bit - 125 Ms/s**)
- **Network connection** for remote access and control
- Low power (**USB**) consumption

The software part is based on the **ABCD** [2] acquisition system, a modular software which includes the following modules for:
- Hardware communication (**digitizer**)
- **Signal shaping** and **online analysis** (Pulse Height and time info)
- Data saving
- Visualizing **waveforms and spectra in real time**

IT IS SUITABLE FOR A MODERN PORTABLE PHYSICS LAB IN THE EDUCATIONAL CONTEXT.

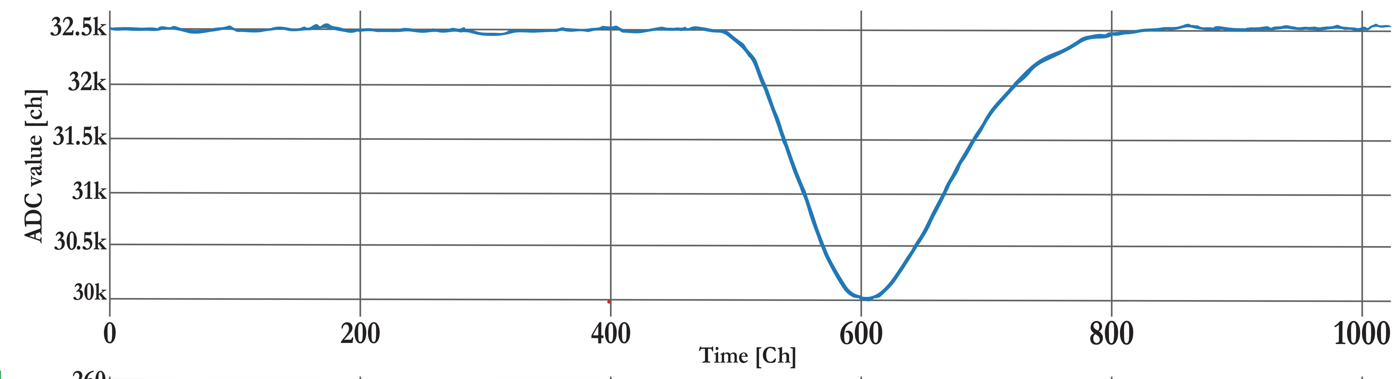
2 Example 1 - Alpha spectroscopy

In-vacuum **alpha-spectroscopy** using a Si PiN diode. The **analog signal** coming from the detector is sent to a preamplifier and then directly **plugged into the Red Pitaya** acquisition board. The **vacuum is crucial** in order to let **alpha particles reach the detector without degradating too much in energy**.

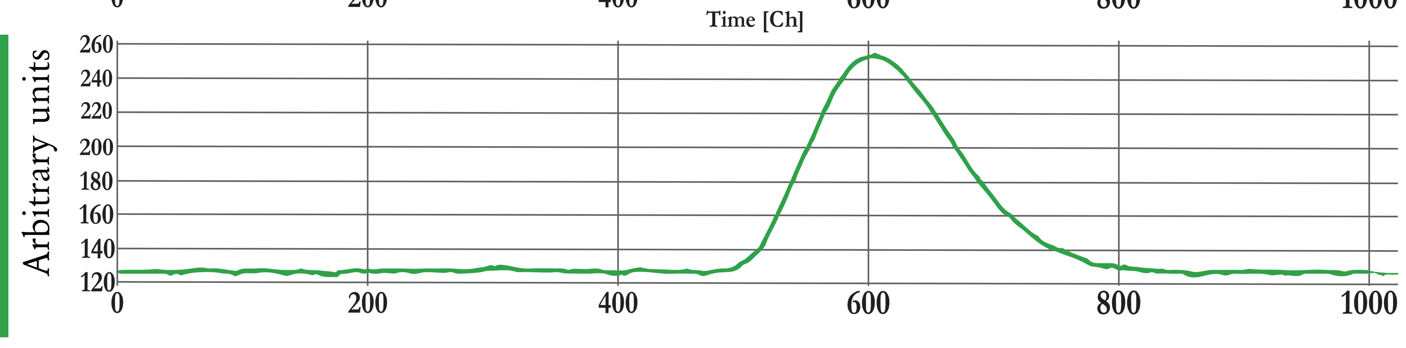


The **analog signal** coming from the pre-amp is **sampled every 8ns** by the ADC

Original analog signal digitized by the ADC. **There is a lot of pre-trigger** in order to better **estimate the baseline.**



Signal shaped by a RC4 software filter. Ater subtracting the baseline, the **time** information and **the pulse height are computed.**

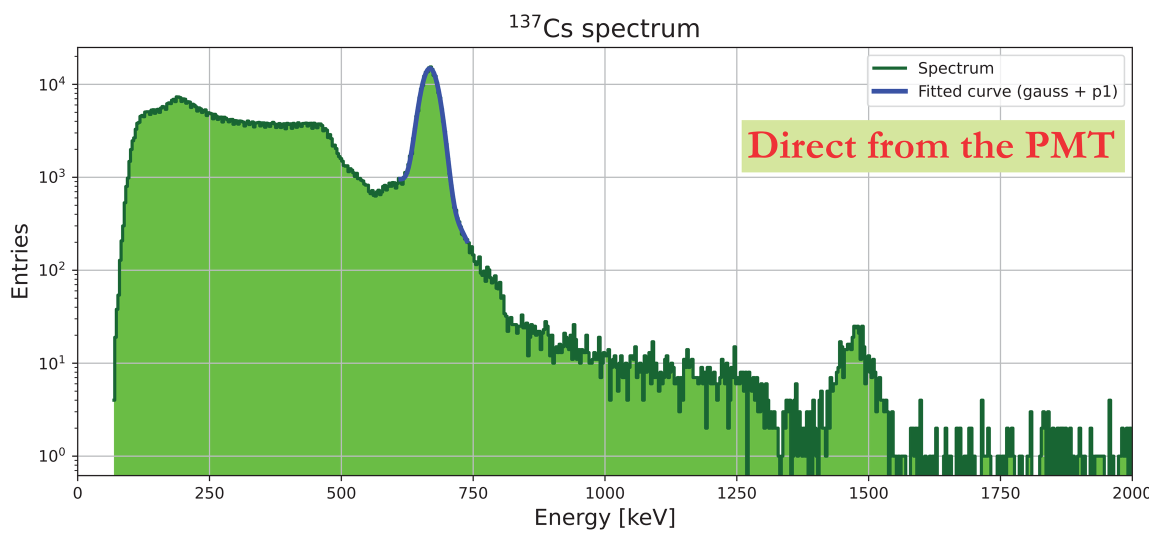


During the nuclear and subnuclear laboratory course, students were asked to **estimate the age of the ^{226}Ra radioactive source** and to study the energy deposit as a function of the pressure for a ^{241}Am source, from which the **dE/dx** can be easily computed.

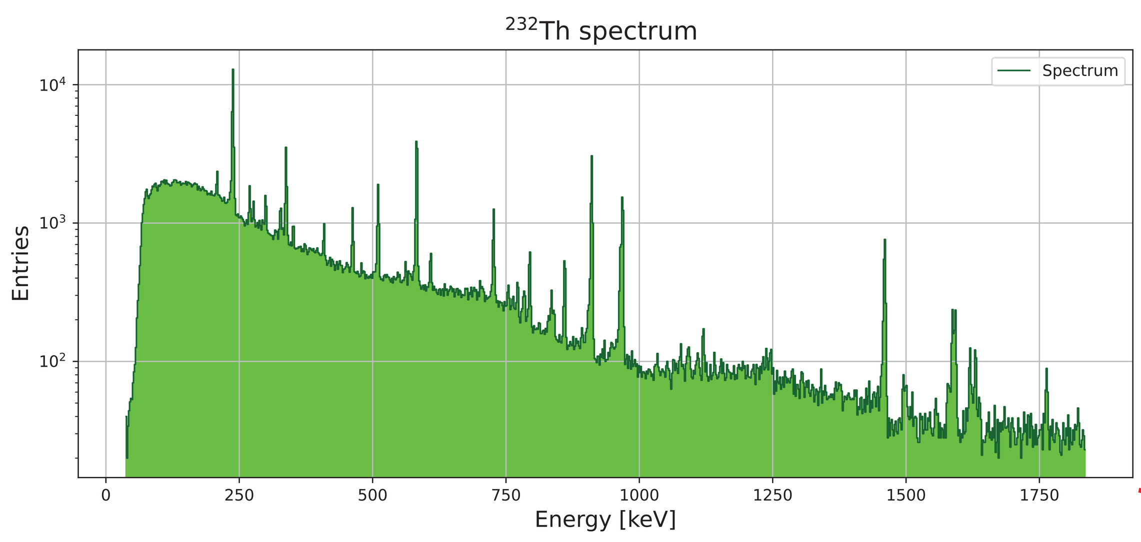
3 Example 2 - Gamma spectroscopy

Gamma-spectroscopy with a **$LaBr_3$ scintillator readout by a PMT.** By acquiring spectra of different radioactive sources, students could perform the calibration of the system and identify the presence of radioisotopes in samples of fertilizer, tufo stone and phosphorite.

The energy resolution measured with the $LaBr_3$ scintillator at 661 keV (the peak of ^{137}Cs, which is a **standard for inorganic scintillators)** is 5.4%, which resulted comparable to the one obtained with the traditional spectroscopic system (5.2%).



High-resolution gamma spectroscopy with a Nitrogen-cooled **Germanium detector.**



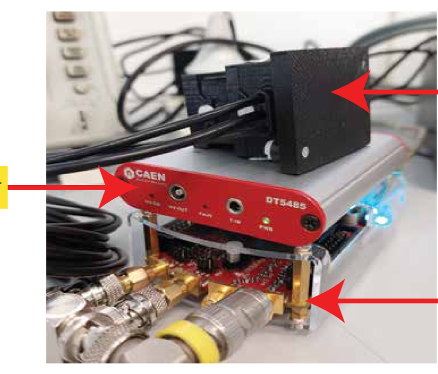
Electrodes

Thoriated welding electrodes (2% ^{232}Th) were used a radioactive source; they can be a good choice for **a system in a school** or for a **portable physics lab**. Furthermore, ^{232}Th has **lots of** clearly identifiable **peaks**: it can be used as a **calibration source.**

Energy resolution for different energy peaks

Energy peak (keV)	Energy Resolution (%)
238	0.9870
338	0.6837
510	0.5532
583	0.4353
727	0.3467
794	0.3392
860	0.3007
911	0.3017
968	0.2932
1460	0.2141

1.27x1.27x1.27 cm^3 **$LaBr_3$ scintillating crystal** readout by 2x2 **SiPiM matrix**, powered by the **CAEN DT5485P** [3], a **single-channel power supply**, whose main features are:
- **20÷85 V (10 mA)** output range with **very low ripple**
- **powered and controlled by USB** (in particular it can be controlled by the Red Pitaya)
- Compact size
- Programmable **temperature compensation**



4 Conclusions

The **system performance** resulted to be **equivalent** to the one obtained with the **traditional VME spectroscopic system.** With the system we propose, one can perform measurements like in an university nuclear physics lab, with a **low-cost compact system,** which is **versatile** (you can **connect** to it **any particle detector**) and portable, making it **ideal** also for **high school laboratories.**

The **data can be easily visualized and processed** with any program (like Python or excel). There are many possibilities for access and analyze the data:
- Open a **Jupyter notebook** directly on the Red Pitaya board and access with a device on the same network
- **Save the data** on a network folder or **on a USB drive**
- **Mount via sshfs** a folder of the Red Pitaya on your personal PC

References: [1] Red Pitaya STEMlab 125-14, URL: https://redpitaya.com/stemlab-125-14 [2] C.L. Fontana, abcd github repository, URL: https://github.com/ec-jrc/abcd [3]:CAEN DT5485P power supply, https://www.caen.it/products/dt5485p

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