PROCEEDINGS OF SCIENCE

Building a nuclear physics lab in the 21st century

Carsi Stefano,[a,b,*] **Bomben Luca,**[a,b] **Fontana Cristiano L.,**[c] **Lezzani Giulia,**[a] **Monti-Guarnieri Pietro,**[a,b] **Petroselli Christian,**[a] **Perna Leonardo,**[a] **Prest Michela,**[a,b] **Ronchetti Federico,**[d] **Saibene Giosuè,**[a,b] **Selmi Alessia**[a,b] **and Vallazza Erik**[b]

[a] *Dipartimento di Scienza e Alta Tecnologia, Università degli Studi dell'Insubria, Via Valleggio 11, Como, Italy*

[b] *Istituto Nazionale di Fisica Nucleare, sezione di Milano Bicocca, Milan, Italy*

[c] *European Commission, Joint Research Centre (JRC), Geel, Belgium*

[d] *École Polytechnique Fédérale de Lausanne, Lausanne, CH*

E-mail: scarsi@studenti.uninsubria.it, stefano.carsi@cern.ch

For more than half a century, expensive and bulky modules (e.g. the standard NIM, Nuclear Instrumentation Modules) and electronic boards have been used in nuclear physics laboratory courses, in order to filter, shape and digitize the analog signals coming from particle detectors. Recently it has become technically possible to miniaturize these circuits within ASICs, but their high cost and specificity make them unsuitable in a didactic and general-purpose context. In this contribution we present an innovative system for reading and processing the signals produced by radiation detectors, which is based on simple, cheap and versatile components. The system is based on the "Red Pitaya STEMlab 125-14" a compact size board which implements: a CPU, a FPGA, a port for network connections (useful for remote access and control) and two 125 MS/s 14-bit digitizer channels. The software framework, necessary for the acquisition, processing, and storage of the signals, is based on the "ABCD" acquisition system. This system was experimentally tested in the Nuclear Physics Laboratory course of the Bachelor's Degree in Physics at the Insubria University, in Como (Italy). In particular, it was used to read the signals produced by a silicon photodiode and a Ce:$LaBr_3$ scintillator in alpha and gamma spectroscopy experiments. The system performance resulted to be equivalent to the one obtained with the traditional VME spectroscopic system. The main advantages of this new approach concern the compactness, versatility, and low cost, making it ideal also for high school laboratories.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

[*]Speaker

PoS(ICHEP2022)1110

1. Introduction

Particle detectors are *glasses* that allow us to *see elementary particles* and how they interact with matter. However, we cannot directly see these particles, but just the product of their interactions with detectors, which normally consists of an electric signal. To extract the needed information analog signals have to be filtered, amplified, shaped and finally digitized.

In the last decades these processes have been standardized and implemented in a variety of electronic modules, one for each task. These modules are typically quite heavy and bulky and thus they are unsuitable to perform particle physics experiments in a didactic context outside the university lab.

In this contribution we present a compact, low cost and versatile system with the entire chain of signal acquisition and processing in a single unit and its application in the context of a didactic gamma-spectroscopy experiment with a Ce:$LaBr_3$ *scintillating crystal* readout by Silicon PhotoMultipliers [1].

The system has been developed both for the nuclear and subnuclear Physics lab of the Bachelor's degree and for an intense program of activities in high schools.

2. The experimental setup

The whole system consists of two main parts: the *hardware* one for the signal acquisition and the *software* one for the signal processing and the physical-quantities computation.

The *electronic and readout part* is based on the Red Pitaya STEMlab 125-14 [2], a cheap board which implements in the size of a credit card:

- a **CPU** Dual-Core ARM Cortex-A9 MPCore
- a **FPGA** Xilinx Zynq 7010
- an **ethernet port** (RJ-45) for the network connection (1Gbit), allowing the system *remote control*
- two *fast* (125 MS/s) and *high-resolution* (14 bit) **analog inputs**, which can operate in the ±1 V or ±20 V range
- a USB 2.0 type A port for the device connection
- a **micro USB** port for the *power delivery*
- a **SD card** with Linux OS.

The *signal shaping and processing part* is fully performed via *software* and relies on ABCD [3], a modular data acquisition system, which offers:

- a **digitizer** module for the *hardware communication* with the Red Pitaya board, where a few acquisition parameters may be set, such as the trigger threshold, the polarity of the trigger signal and the pre-trigger used for the baseline calculation

- a **signal shaping** module which allows to apply *different filters* to the analog signal, such as the RC^n low-pass filter or the CR-RC band-pass filter.
- an **online analysis** module which can compute different quantities like Pulse Height (PH), Time Over Threshold (TOT), peak integral or Time Of Flight (TOF)
- a **data saving** module, which defines whether to save only the online-computed physical quantities, or the entire waveforms
- modules for visualizing *waveforms and spectra in real time*.

The experiment detector was a 1.27x1.27x1.27 cm^3 Ce:LaBr$_3$ *scintillating crystal*, readout by a 2x2 12x12 mm^2 Silicon PhotoMultipliers (SiPMs) matrix [1]. The bias for the SiPMs was provided by the CAEN DT5485P [4], a single-channel power supply which can provide up to 10 mA in the 20÷85 V range with a very low ripple. The CAEN module is compact and it can be controlled via USB, plugging it to the USB port of the Red Pitaya board. The complete system can be controlled remotely with a PC that has to be connected to the same network. The experimental setup is shown in figure 1.

Although any radioactive gamma-emitting source might be used, we decided to use *welding electrodes*: in fact, most of them contain 2% of ^{232}Th which can be used as the calibration source. Furthermore welding electrodes are not even considered a radioactive source and therefore there are no radioprotection nor safety problem in handling them.

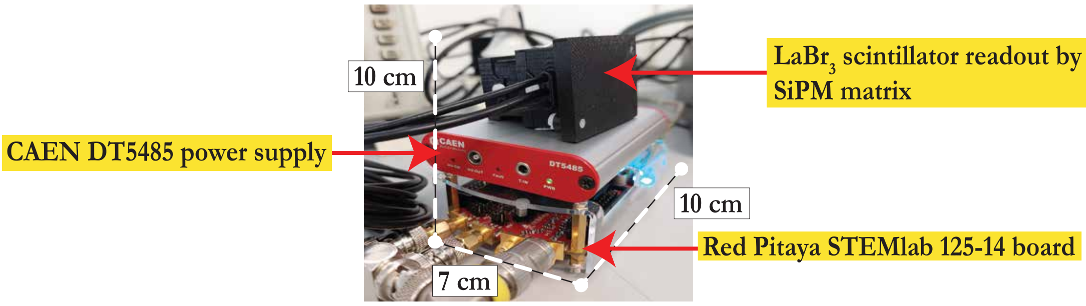

Figure 1: Experimental setup: from bottom to top: Red Pitaya STEMlab 125-14 board, CAEN DT5485P power supply and Ce:LaBr$_3$ scintillator readout by a 2x2 SiPM matrix.

3. Results

The analog signal coming from the SiPMs was directly plugged into the Red Pitaya acquisition board. To ensure the acquisition of the whole signal and, given a low enough trigger rate, a window of 1024 samples was acquired, with a pre-trigger of 350, in order to better estimate the baseline and therefore the pulse height.

The *energy resolution* (FWHM) can be measured acquiring the spectrum of a ^{137}Cs source (figure 2), whose peak (661 keV) is the standard reference for inorganic scintillators. The resolution

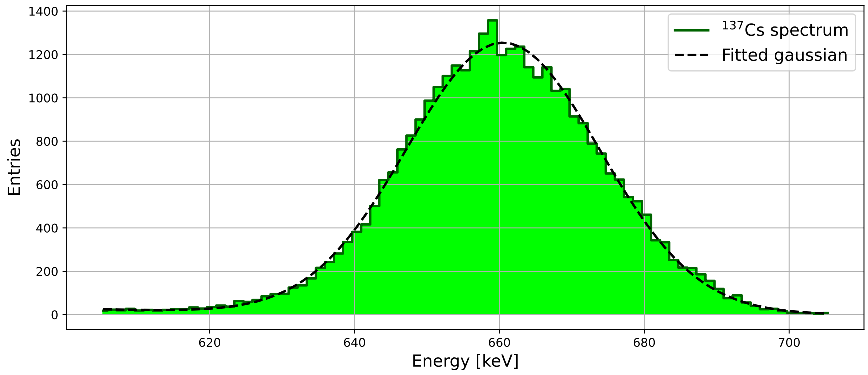

Figure 2: Gamma spectrum of a ^{137}Cs source, acquired with Ce:$LaBr_3$ scintillating crystal readout by a 2x2 SiPM matrix, to measure the energy resolution.

resulted to be 4.8%, which is close to 3.5%, the one obtained with the traditional VME system [1], with NIM modules for amplifying, shaping and sampling the analog signals.

4. Conclusions

The Red Pitaya STEMlab 125-14 system performance resulted to be equivalent to the one obtained with the traditional VME spectroscopic system. The system is a low-cost, versatile, compact and portable system, that can be connected to different types of particle detectors. These features allow to implement a modern spectroscopic lab both for a university course and inside high schools.

The data can be easily visualized and processed with any programming software (like Python or Excel): for high school applications, analysis templates can be provided to the students to help them with the analysis phase. In this way more attention may be given to the physical phenomena underlying the experiments, rather than the more technical aspects of the data acquisition system, since these may not be the main focus of the lesson itself.

We believe that bringing modern physics into the school in a pratical and comprehensive way is very important and the system we present is an excellent resource for pursuing this aim.

References

[1] *M. Bonesini et al.*, 2020 JINST 15 C05065, URL: https://iopscience.iop.org/article/10.1088/1748-0221/15/05/C05065

[2] *Red Pitaya Stemilab 125-14,* URL: https://redpitaya.com/stemlab-125-14/

[3] C. Fontana, *abcd github repository,* URL: https://github.com/ec-jrc/abcd/

[4] CAEN DT5485P Power supply, URL: https://www.caen.it/products/dt5485p