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108° Congresso Nazionale della Società Italiana di Fisica



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Characterization of a compact and
cost-effective readout system for
germanium detectors

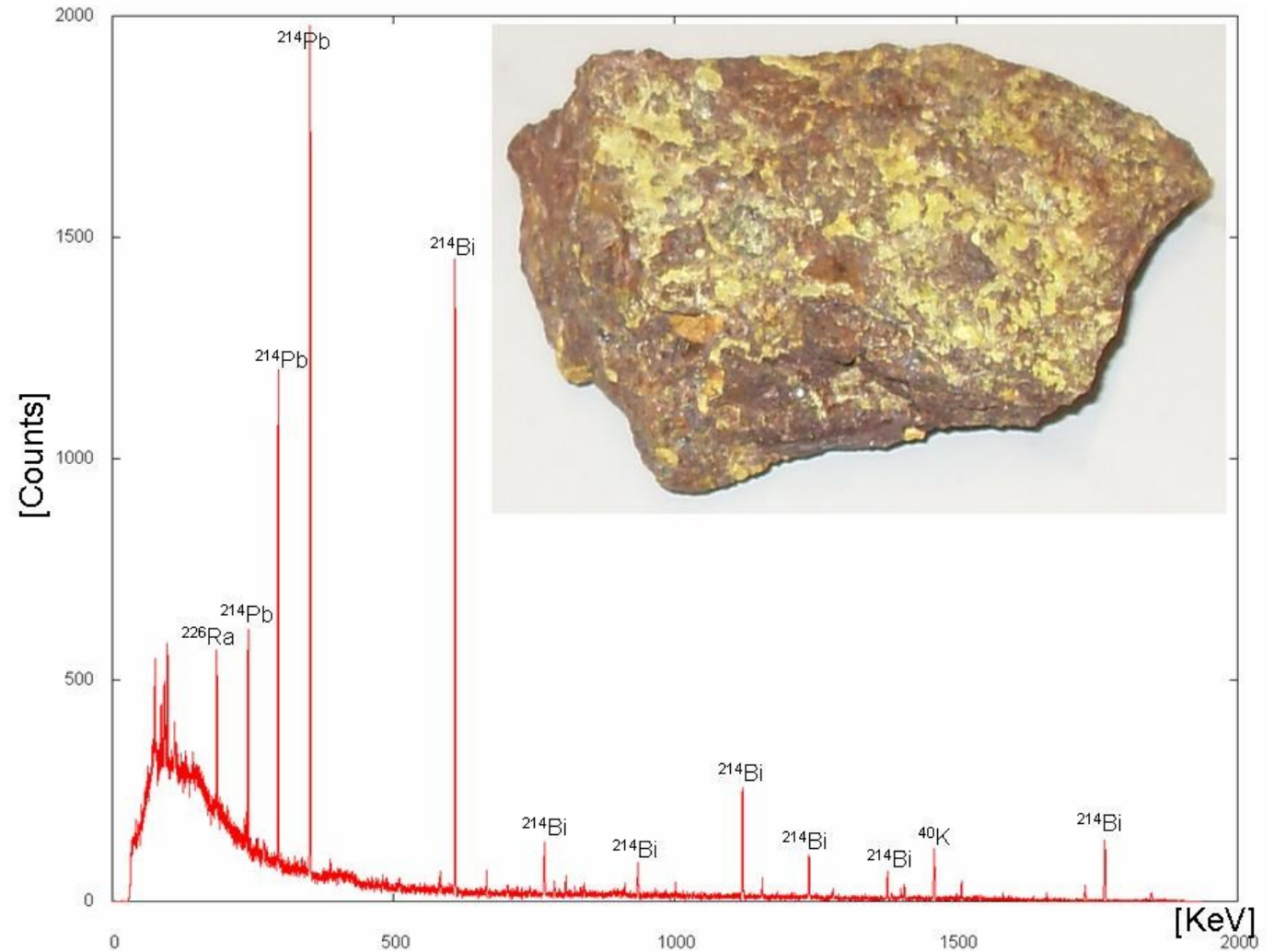
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Sommario

- Introduzione alla **spettroscopia gamma**
- Cenno al **sistema tradizionale** di acquisizione
- Descrizione del nuovo sistema
 - **Hardware**: scheda Red Pitaya STEMLab 125-14
 - **Software**: abcd framework
- Presentazione di **alcuni spettri**
- Calcolo della **risoluzione energetica**
- **Conclusioni**

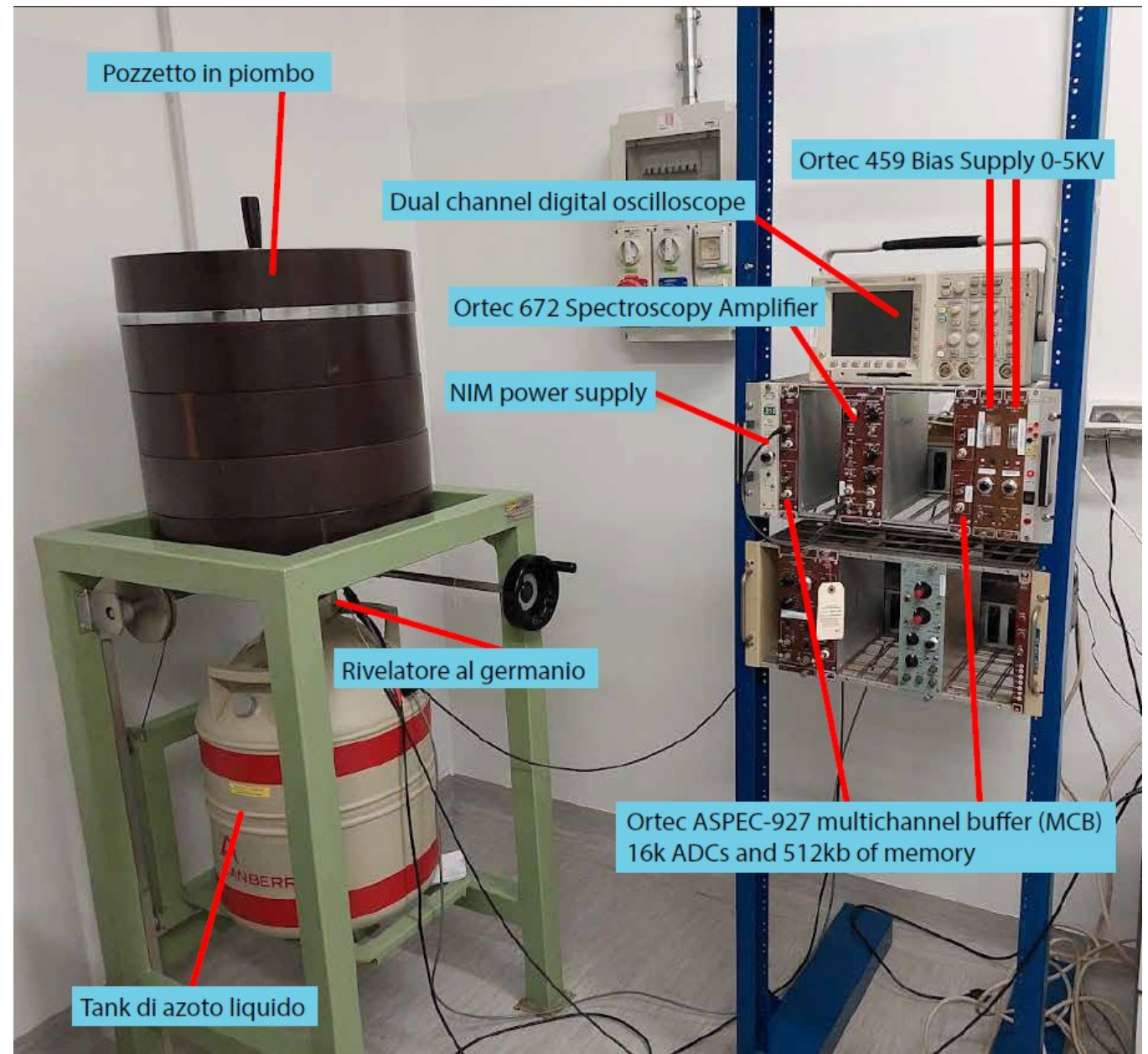
Spettroscopia gamma

- **Spettroscopia gamma**: misurare l'energia di fotoni emessi da varie sorgenti radioattive
- Due tipologie
 - Bassa risoluzione: con **scintillatori inorganici** (più diffuso NaI:TI)
 - Alta risoluzione: **rivelatori a semiconduttori**
- Rivelatori al **germanio ad alta purezza** (HPGe): eccellente risoluzione energetica MA **devono essere raffreddati** con azoto liquido



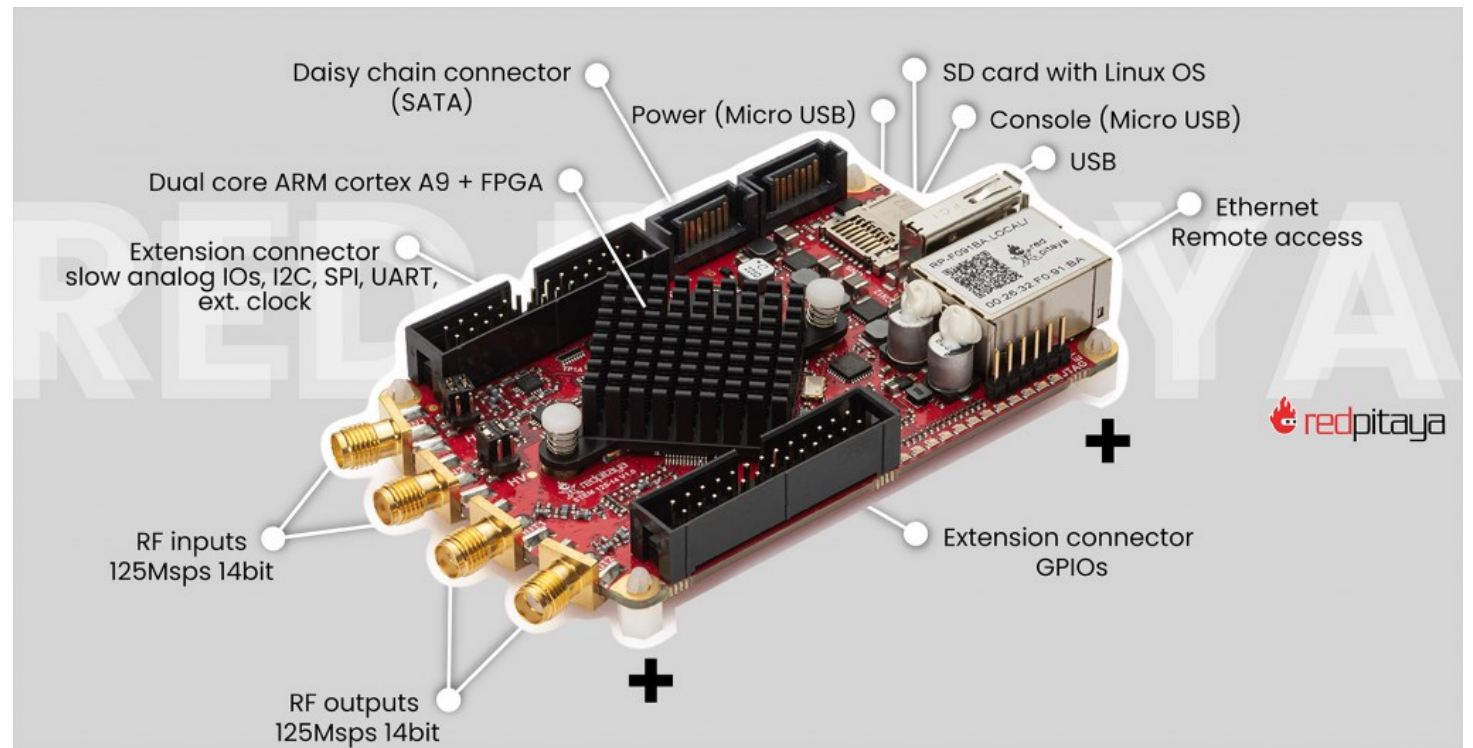
Il sistema tradizionale di acquisizione

Il **segnale** proveniente dal **preamplificatore** del rivelatore al germanio viene **formato** (Ortec 672) e **digitalizzato** da moduli NIM (Ortec 927 connesso a **PC via USB**, compatibile con il software MAESTRO)



La scheda Red Pitaya STEMLab 125-14

- **FPGA** e **CPU** (con Linux OS)
- Porta di rete per **controllo remoto**
- Alimentazione **USB**
- Due **ingressi veloci** (125 MS/S) ad **alta risoluzione** (14 bit)
- **Dimensioni compatte** e **costo ridotto**



Il sistema di acquisizione ABCD

Sistema di acquisizione modulare, che comprende

- Modulo per **comunicazioni hardware**, dove **impostare trigger** e **finestra di acquisizione**
- Modulo per **filtraggio del segnale** ed **analisi online**
- Modulo per il **salvataggio dei dati**
- Modulo per **visualizzare** in tempo reale **forme d'onda** e **spettri**

ABCD is
a distributed
Data Acquisition System
<https://github.com/ec-jrc/abcd/>

ABCD data acquisition system

[home](#) [digitizer_interface](#) [waveforms_display](#) [waveforms_analysis](#) [data_saver](#) [spectrum_calculator](#) [ToF_calculator](#)

Digitizer interface

The screenshot displays the 'Digitizer interface' with three main sections:

- Controls:** Includes 'Start' and 'Stop' buttons, a 'Start with timer' checkbox, and an 'Acquisition time [min]:' input field set to 10.
- Status:** Displays system health and performance metrics:
 - Digitizer active: true
 - Acquisition running: true
 - Run time: 1 minute, 23 seconds (83 s)
 - Rates:
 - 1. Ch 0: 1.00
 - 2. Ch 1: 0.00
 - ICR Rates:
 - 1. Ch 0: 1.00
 - 2. Ch 1: 0.00
 - Average rates:
 - 1. Ch 0: 0.19
 - 2. Ch 1: 0.00
 - Total counts:
- Digitizer configuration:** Features 'Send configuration', 'Get configuration', and 'Download configuration' buttons. Below is a JSON configuration editor with line numbers 1-16. Three orange arrows point from the 'Controls' section to the configuration JSON:
 - Arrow 1 points to line 10, where the 'trigger' object is defined.
 - Arrow 2 points to line 11, where 'scope_samples' is set to 4096.
 - Arrow 3 points to line 12, where the 'channels' array is defined.

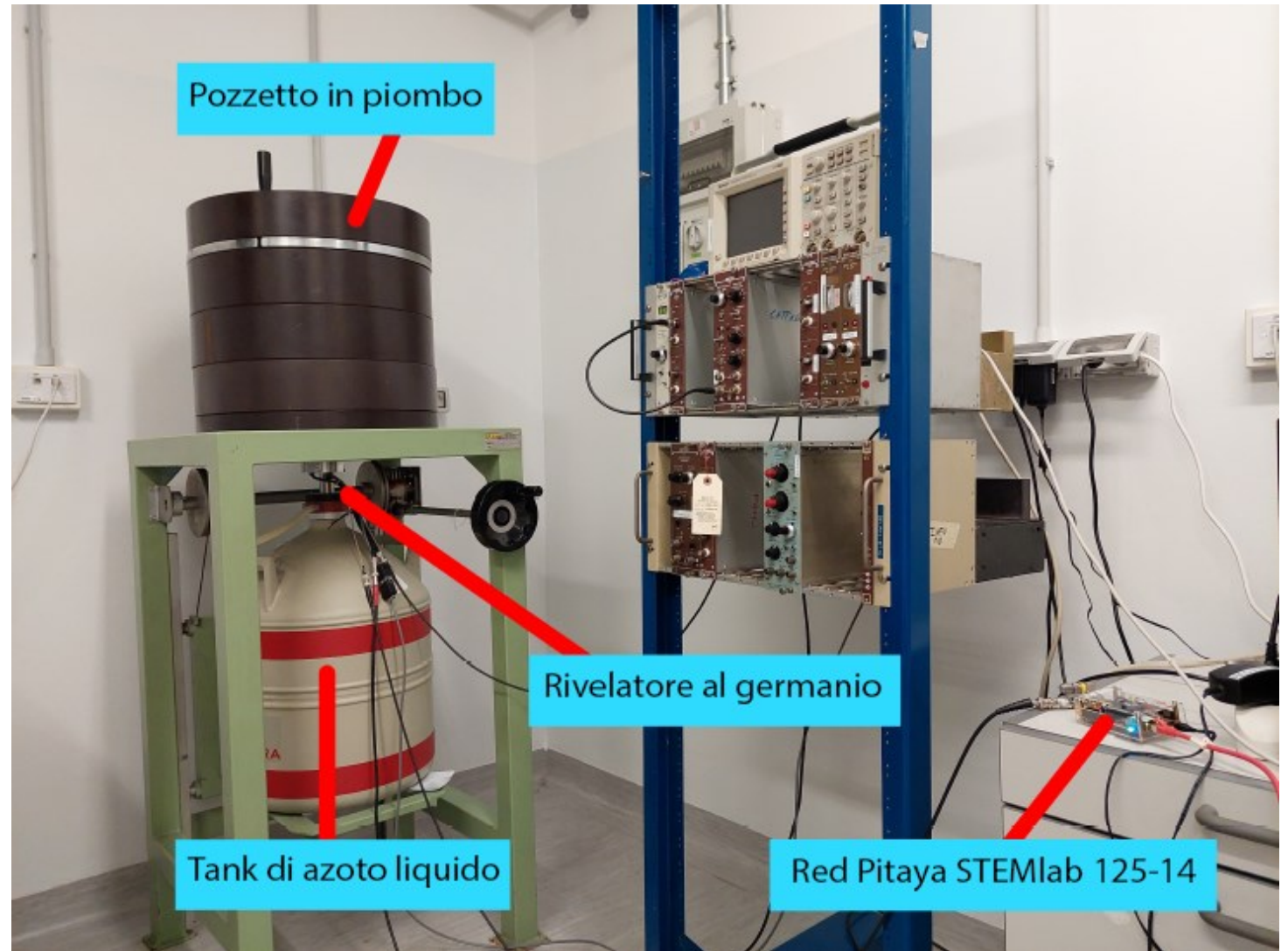
Sorgente radioattiva

- Elettrodi da saldatura, con un **2% di ossido di ^{232}Th**
- Dal punto di vista delle emissioni gamma hanno **un'intensità adeguata** per acquisire uno **spettro di calibrazione**
- Dal punto di vista radioprotezionistico, **non sono** nemmeno **classificati come sorgente**. Sono dunque assolutamente **sicuri e facilmente trasportabili** ed usabili in una **scuola** o in un **laboratorio portatile**



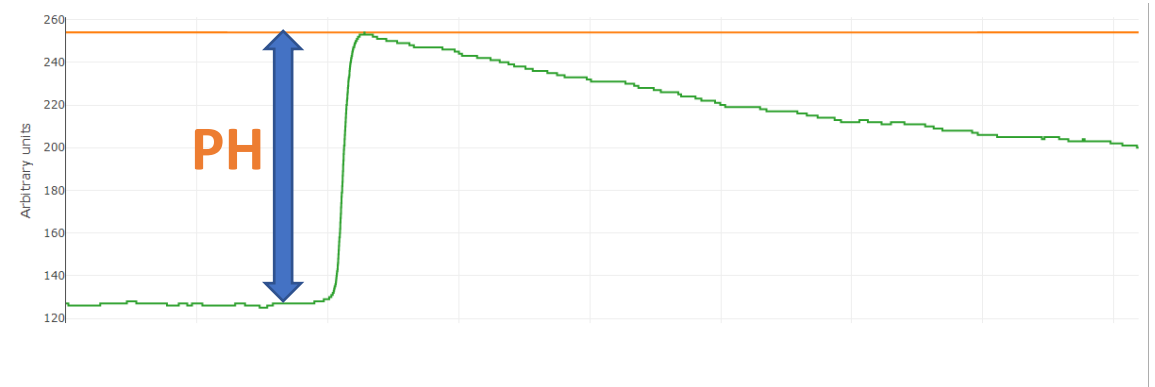
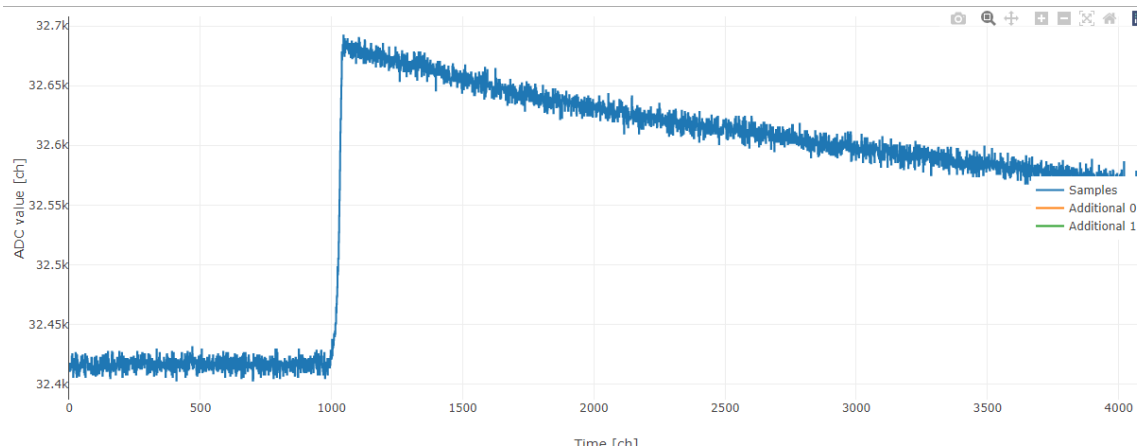
Setup sperimentale @ Bicocca

- Sinistra: rivelatore al germanio ad alta purezza (HPGe) con **schermatura in piombo** e tank di **azoto liquido** per raffreddare
- Il **segnale** proveniente dal preamplificatore viene **inserito direttamente nella scheda** Red Pitaya STEMLab 125-14



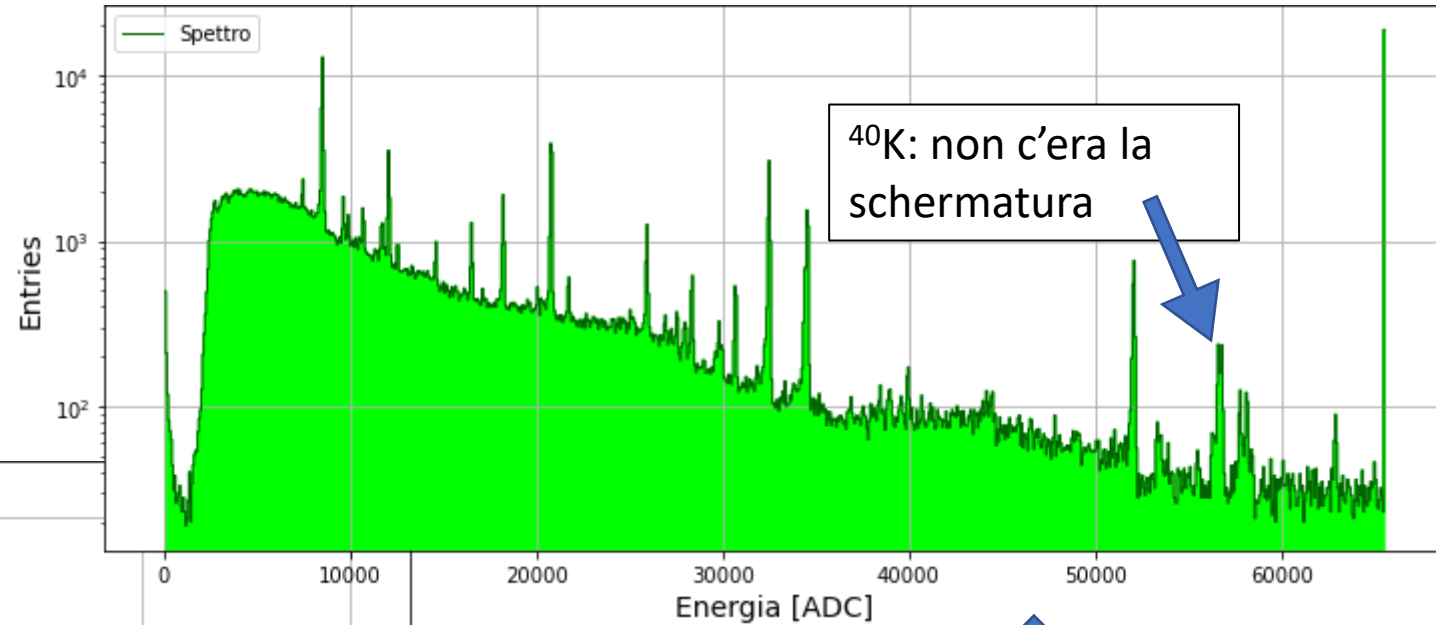
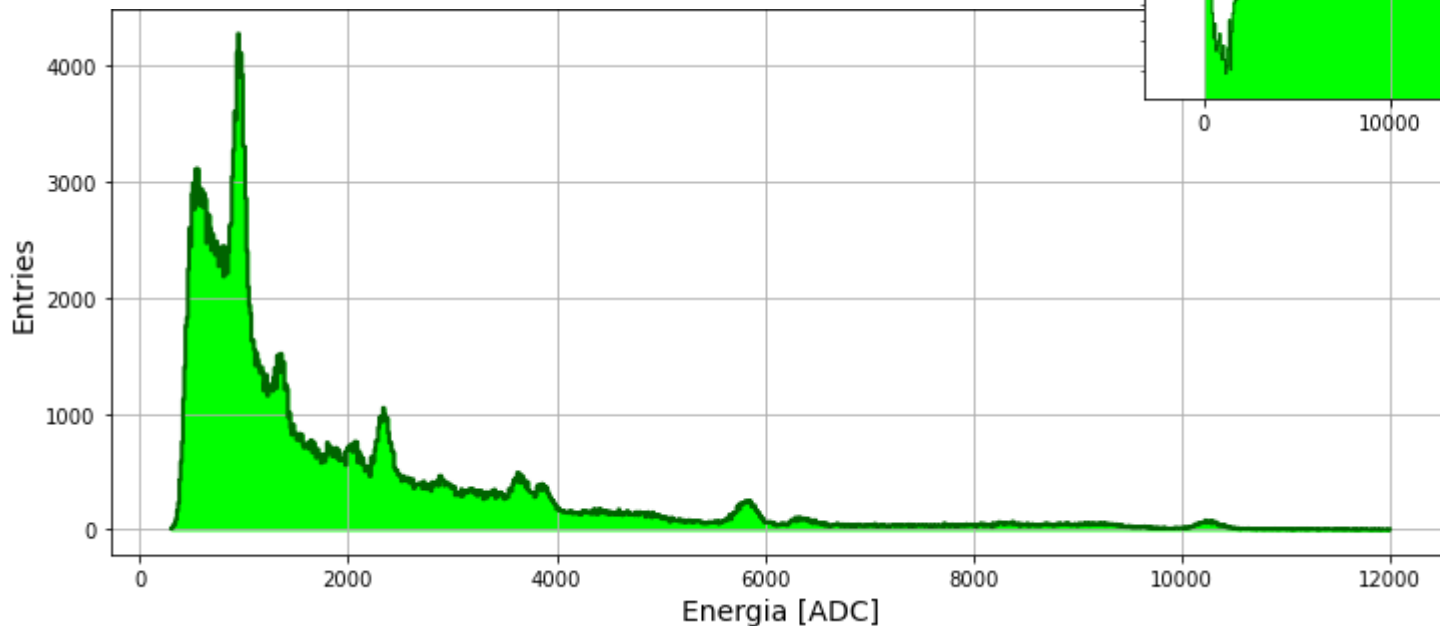
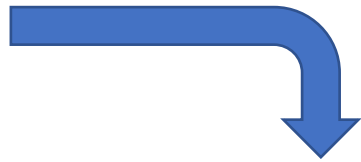
Acquisizione della forma d'onda

- La forma d'onda viene acquisita con un **pre-trigger** sufficiente a stimare la **baseline**
- La **pulse height**, valore proporzionale all'energia depositata, viene calcolata come **differenza** tra il **massimo del segnale** e la **baseline**, dopo aver applicato **algoritmi di filtraggio**

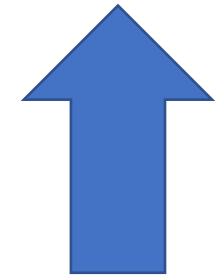


Stessa sorgente – diverso rivelatore

Spettro acquisito con un
bromuro di lantanio LaBr_3
(**Scintillatore inorganico**)

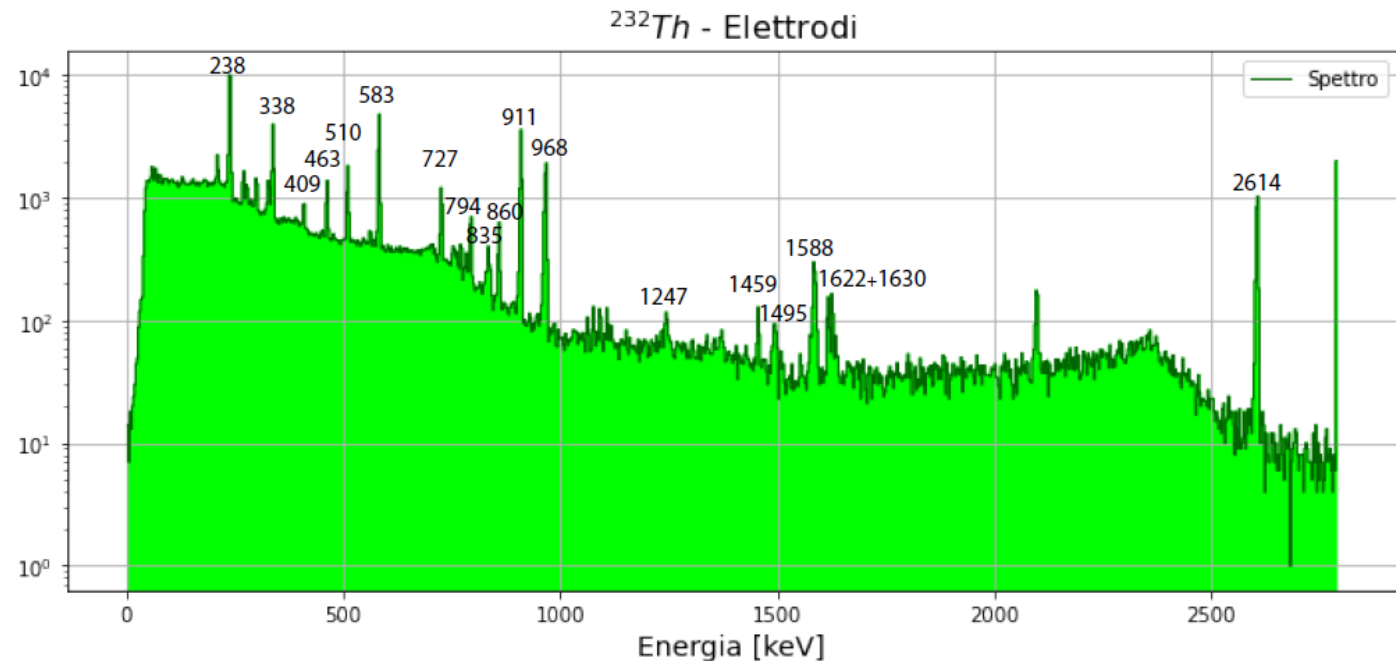
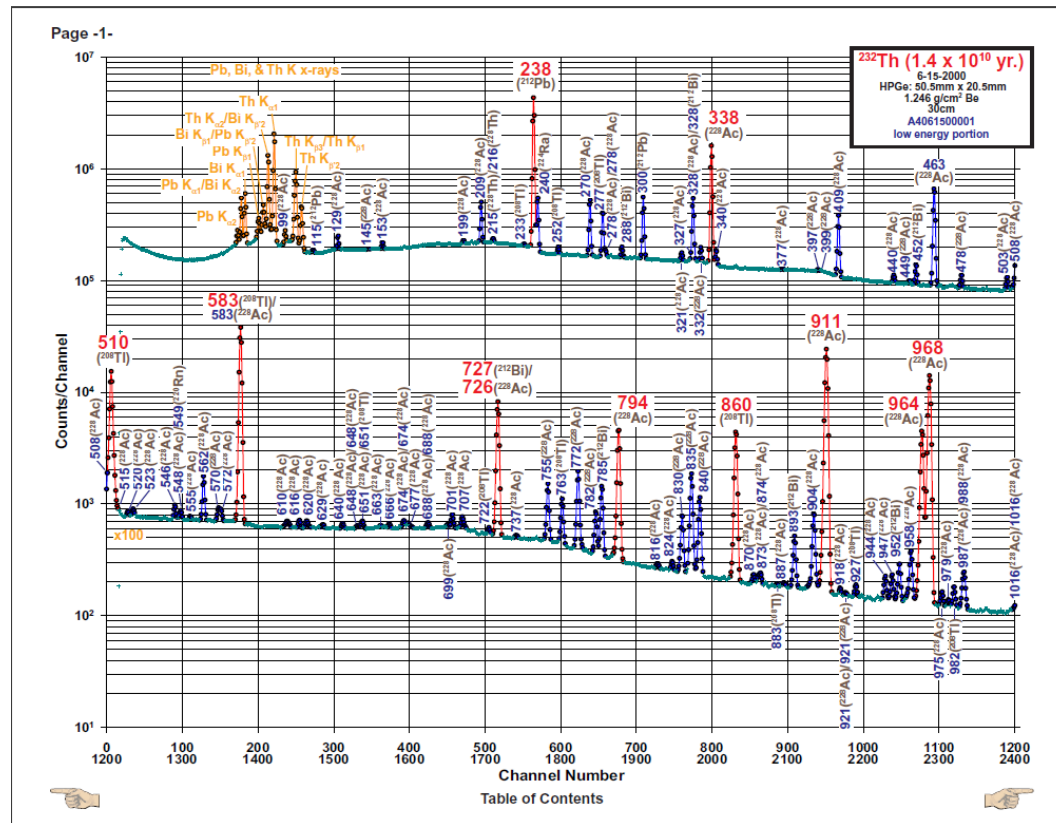
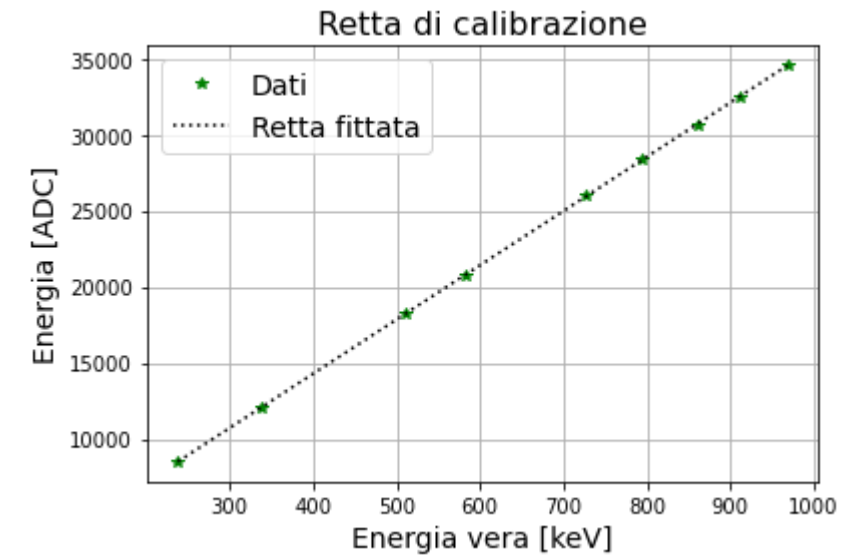


Spettro acquisito con un
germanio ad alta purezza
HPGe (**semiconduttore**)



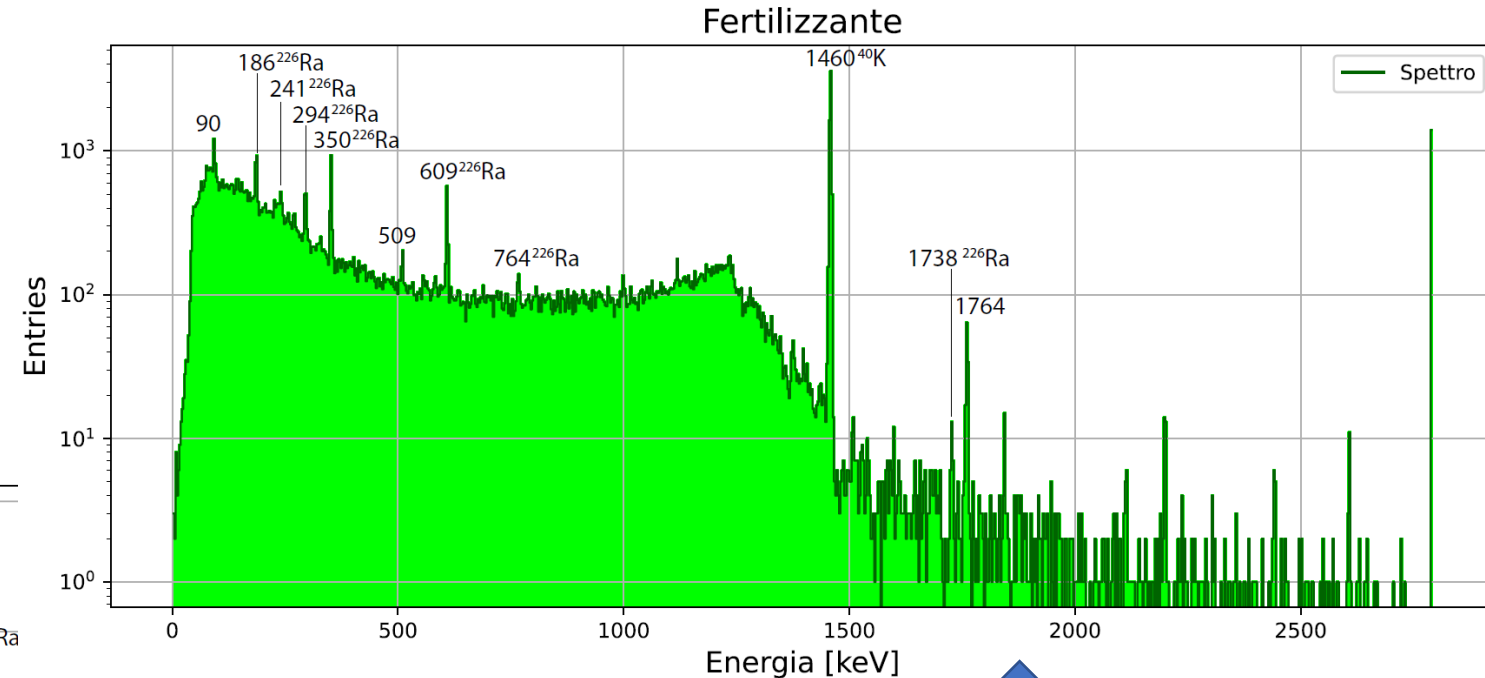
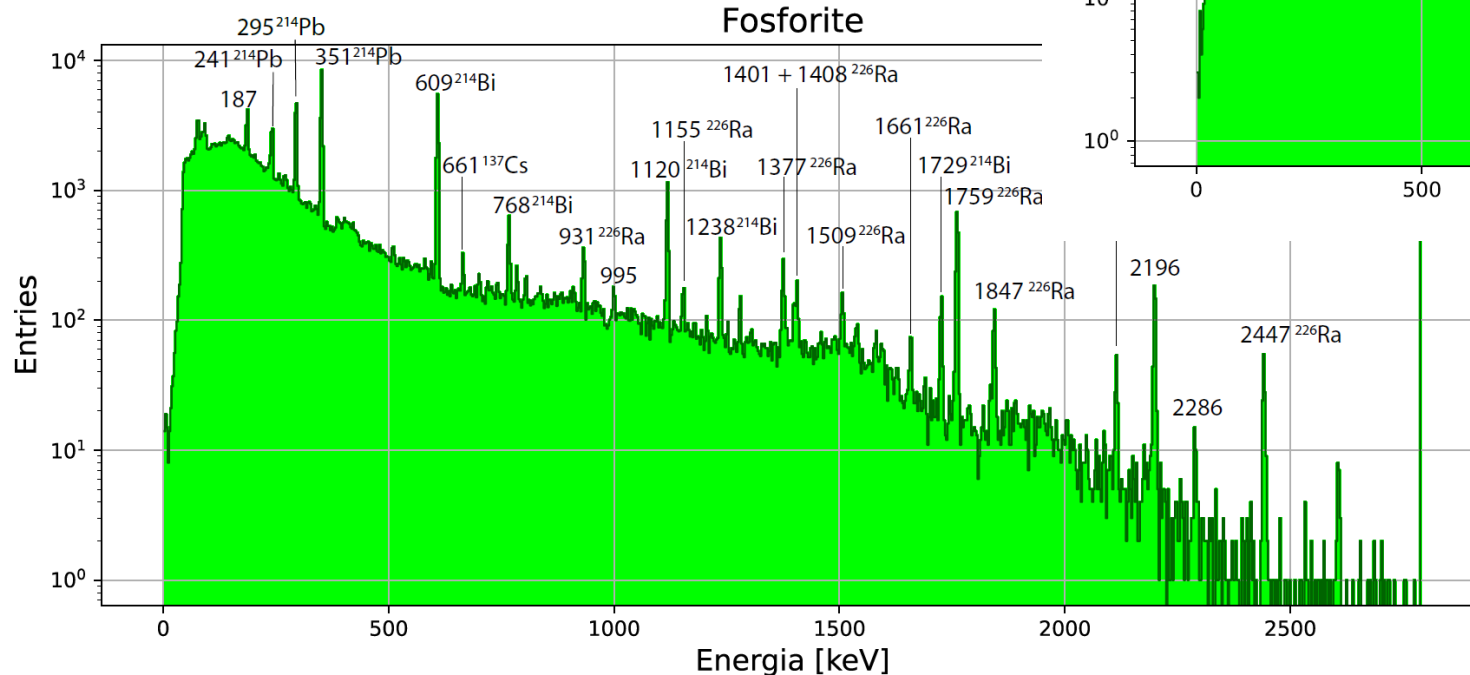
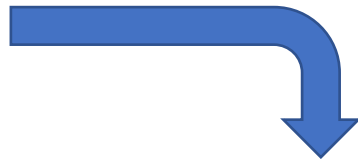
Calibrazione dello spettro

- Si **associa ad ogni picco** individuabile nel proprio spettro l'energia ottenuta consultando uno **spettro di riferimento**
- Si trova la funzione (**retta di calibrazione**) che permette di passare da energia in unità di ADC ad un'energia in keV



Stesso rivelatore – differenti campioni

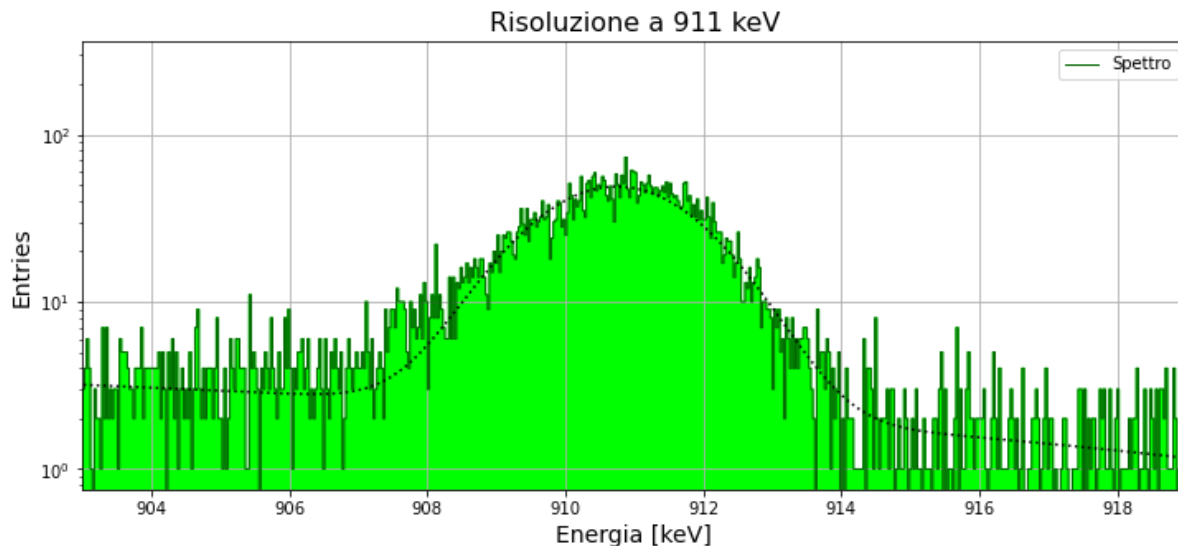
Fosforite: si possono notare picchi degli isotopi di ^{214}Pb e ^{214}Bi appartenenti alla **catena naturale del ^{226}Ra**



Fertilizzante in granuli: si notano, oltre ad alcuni picchi relativi al ^{226}Ra , il picco a 1460 keV del ^{40}K

Risoluzione energetica a diverse energie

- **Calibrazione** dello spettro (da ADC a keV)
- **Fit gaussiano** dei picchi
- **Risoluzione** = $\frac{FWHM}{E} = 2.35 * \frac{\sigma}{E}$



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

Conclusioni

Il sistema presenta **risultati comparabili** a quelli ottenuti col **sistema tradizionale** di acquisizione in termini di **risoluzione energetica** (a 1332 keV: 0.30% vs 0.14%).
Linearità: residui inferiori a 0.1%

I vantaggi di questo nuovo approccio riguardano la **compattezza e la portabilità**

Si possono **salvare le configurazioni**

Si può **controllare** qualsiasi parametro connettendosi **da remoto**

Si possono implementare **filtri e analisi differenti** semplicemente **scrivendo codice**, senza comprare **nessun modulo ulteriore**

Sviluppi futuri

Questo sistema è inoltre **molto versatile**: può essere impiegato per **leggere qualsiasi** tipo di **rivelatore di particelle**: può quindi essere utilizzato per attività all'interno di **scuole** o per **laboratori portatili** di fisica

I **dati acquisiti** possono essere direttamente processati (p.es. con Python o Excel), fornendo agli studenti **template di analisi** pronti all'uso che permettano agli studenti di **concentrarsi sulla fisica**

Grazie per l'attenzione

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Backup slide

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Poster conferenza ICHEP

- Poster presentato alla International Conference of High Energy Physics (ICHEP)
- Il sistema è in grado di coprire tutti i topic di un laboratorio di fisica nucleare e subnucleare del corso di laurea in fisica

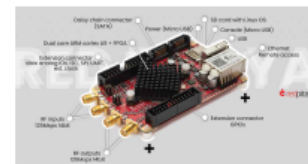
14/09/2022

Building a nuclear physics lab in the 21st century

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³European Commission, Joint Research Centre (JRC), Geel, Belgium

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].



Main features:
 • Compact size (credit card)
 • Integrates 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

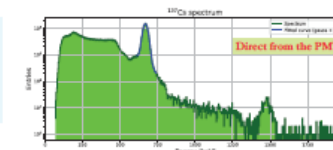
The software part is based on the **ABCD** [2] acquisition system, a modular software which includes the following modules for:
 • Hardware communication (digitizer)
 • Signal shaping and online analysis (Pulse Height and time info)
 • Data saving
 • Visualizing waveforms and spectra in real time

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

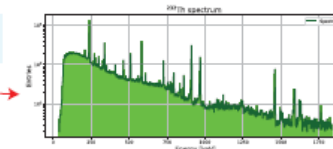
3 Example 2 - Gamma spectroscopy

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, tuff 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.



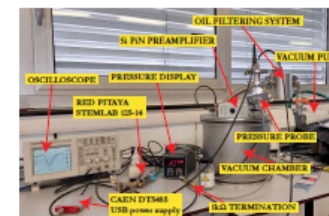
Thoriated welding electrodes (2% ^{232}Th) were used as a radioactive source; they can be a good choice for a system in a school or for a portable physics lab. Furthermore, ^{232}Th has lots of clearly identifiable peaks: it can be used as a calibration source.

Energy resolution for different energy peaks

Energy peak (keV)	Energy Resolution (%)
212	0.9870
218	0.6207
110	0.5522
583	0.4533
727	0.3467
704	0.3380
803	0.3067
911	0.3077
968	0.2903
1460	0.2340

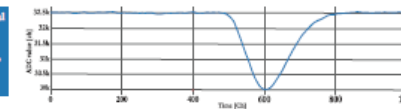
2 Example 1 - Alpha spectroscopy

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 degrading too much in energy.

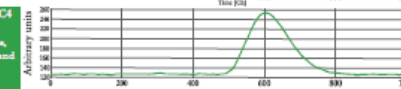


The analog signal coming from the pre-amp is sampled every 8ns by the ADC

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. After 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.

1.27x1.27x1.27 cm³ LaBr_3 scintillating crystal readout by 2x2 SiPM 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 a 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 analysis of 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