Hyper Pure Germanium spectroscopy

Author	J-M. Fontbonne, C. Fontbonne
Address	**LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, Caen, France**
Mail	fontbonne@lpccaen.in2p3.fr cfontbonne@lpccaen.in2p3.fr

Introduction

Hyper Pure Germanium detectors (HPGe) are outstanding devices for radioactivity spectroscopy. In order to take benefit from their full capacities, one must connect them to state of the art signal processing spectroscopy amplifiers and acquisition boards. Creating a numerical spectroscopy amplifier and data acquisition system is a challenging and a really interesting problem.

We will explore, in this FASTER use-case, some results on HPGe spectroscopy, using the CR-RC4 shaper of FASTER.

What will you find in this educational document?

- Some examples of spectroscopy measurements of common radioactive sources
- Some basic performances of the spectroscopy possibilities of FASTER

J-M. Fontbonne, C. Fontbonne, **LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, Caen, France**

1. The device and its electronic

A HPGe detector consists on a high purity germanium crystal directly connected to its charge sensitive preamplifier (in order to lower stray capacitances that amplify series noise coming from the preamplifier), cooled at liquid nitrogen temperature (in order to lower inverse current that creates parallel noise from the detector).

All the spectra below are obtained using our 20 years old good great volume HPGe detector.

2. Data acquisition:

Connecting a HPGe detector to FASTER is really easy. You just have to connect the Charge Sensitive Preamplifier of your favorite detector to a MOSAHR daughter board (14bits, 125MHz). Inputs of this board have an impedance of about 1kΩ. Depending on your application you can select (by hardware, before installation) ±10V, ±5V, ±2V or ±1V input ranges.

The spectroscopy amplifier developed in FASTER data processing and acquisition system contains:

- A “fast out” channel with an integrated CR-RC4 shaper of 25ns or 60ns shaping time constant. This channel can be used to trigger data acquisition and is internally connected to a pileup detector and the spectroscopy base-line restorer.
- A spectroscopy channel with an integrated CR-RC4 shaper with user selectable shaping time ranging from 60ns to 32µs. Depending on user needs, it can produce monopolar signal (best resolution) or bipolar signal (worst resolution but less sensitive to events count rate variations). This channel can also be used to trigger the acquisition (lower energy threshold but worst timing resolution).
- It is equipped with two kinds of base-line restorers. You can either subtract a constant level (constant BLR) or use the Dynamic BLR. The Dynamic BLR follows slow base-line variations on real time with a low cutoff frequency (best resolution) or high cutoff frequency (worst resolution but better result in harsh EMC environments).
- It is connected to a pileup detector which set a flag at 1 if output data is suspected of pileup. This means that, if the pileup bit is set, the energy is probably false. But if the bit is not set, event is probably pileup free.

3. Examples & overall performances

3.1. Radioactive sources decay scheme

The decay schemes of some radioactive sources studied below are drawn on Fig. 1:

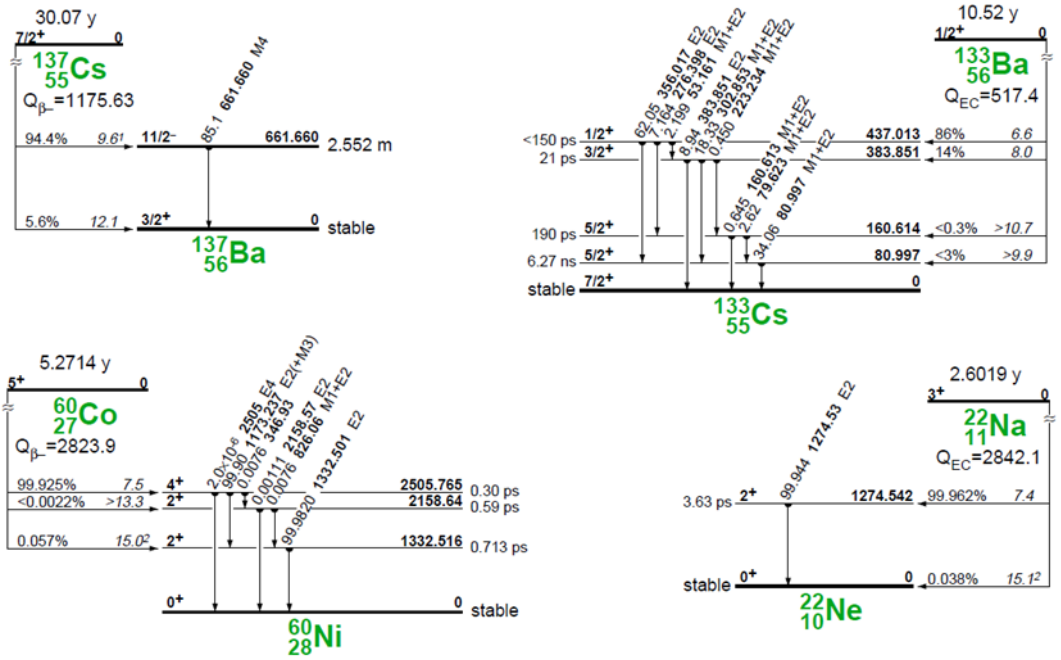
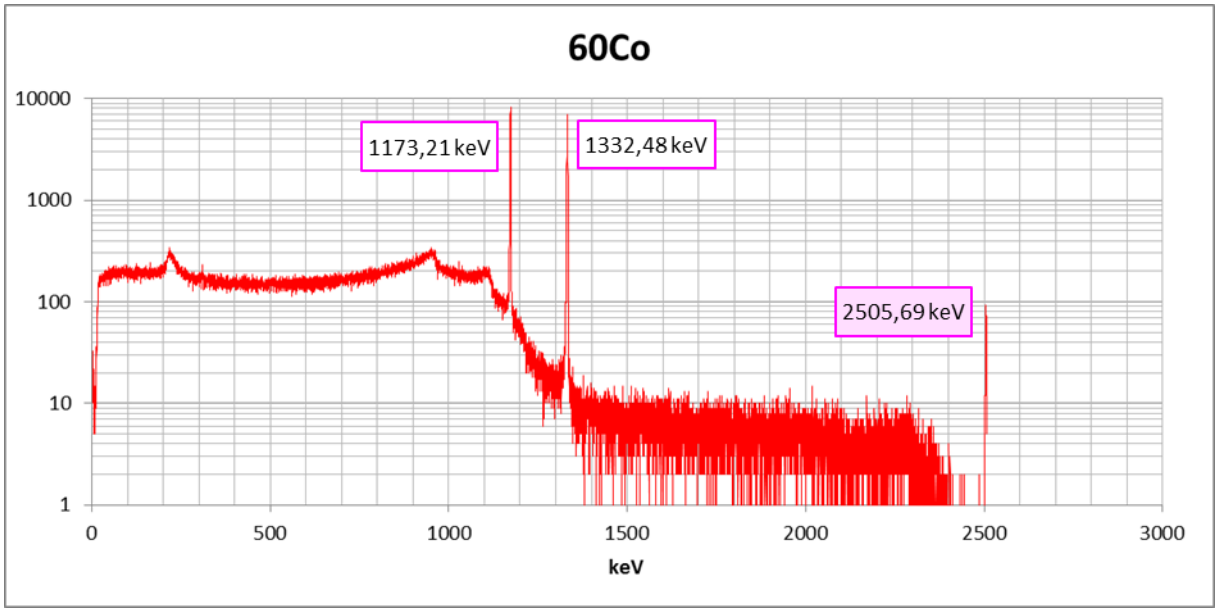


Fig. 1: common radioactive sources decay scheme (from Table of isotopes, Firestone & Shirley)

J-M. Fontbonne, C. Fontbonne, **LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, Caen, France**

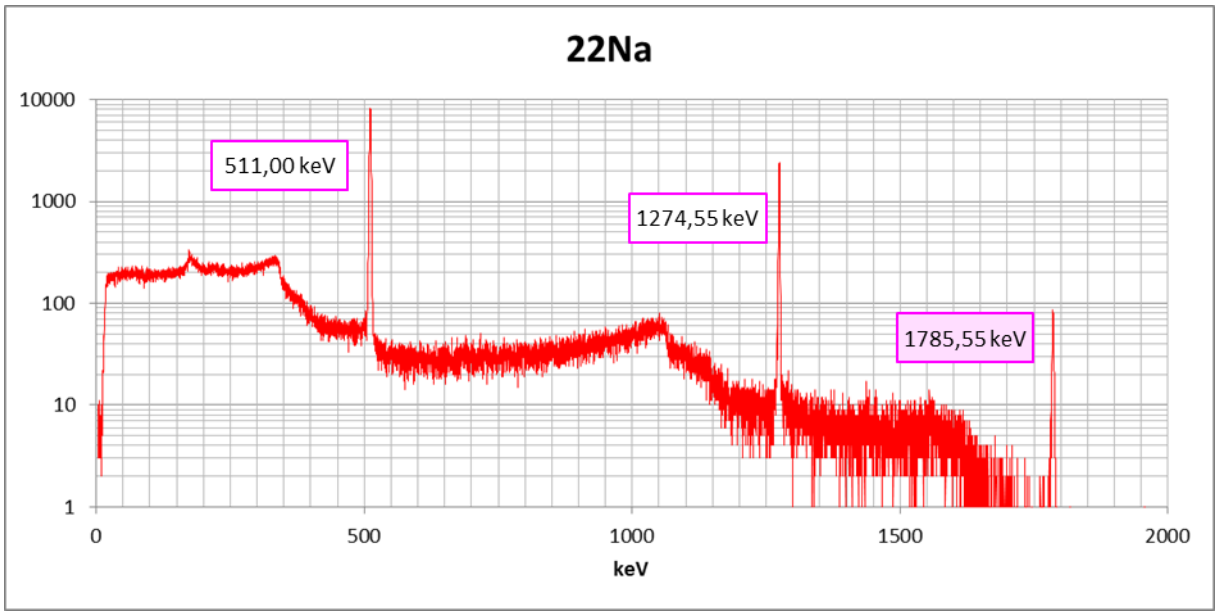
3.2. Spectra of common radioactive sources

The spectra illustrated below where taken using a 4µs shaping time constant.



^{60}Co mainly decreases by emitting two γ in coincidence (resp. 1173 & 1332MeV). Sometimes, these two γ simultaneously interact in the HPGe detector, producing the sum peak at 2505MeV. The resolution is 1.88keV$_{FWHM}$ for the 1173keV peak and 2.08keV$_{FWHM}$ on the 1332keV peak.

---===ooOoo===---



^{22}Na is a β+ emitter. Synchronously, a 1275keV γ is emitted. When the β+ is thermalized, it annihilates with an electron of the surrounding material, producing two 511keV γ emitted in oposite directions. When the first γ and an annihilation γ simultaneaouly interact in the HPGe detecor, they produce the sum peak at 1785keV.

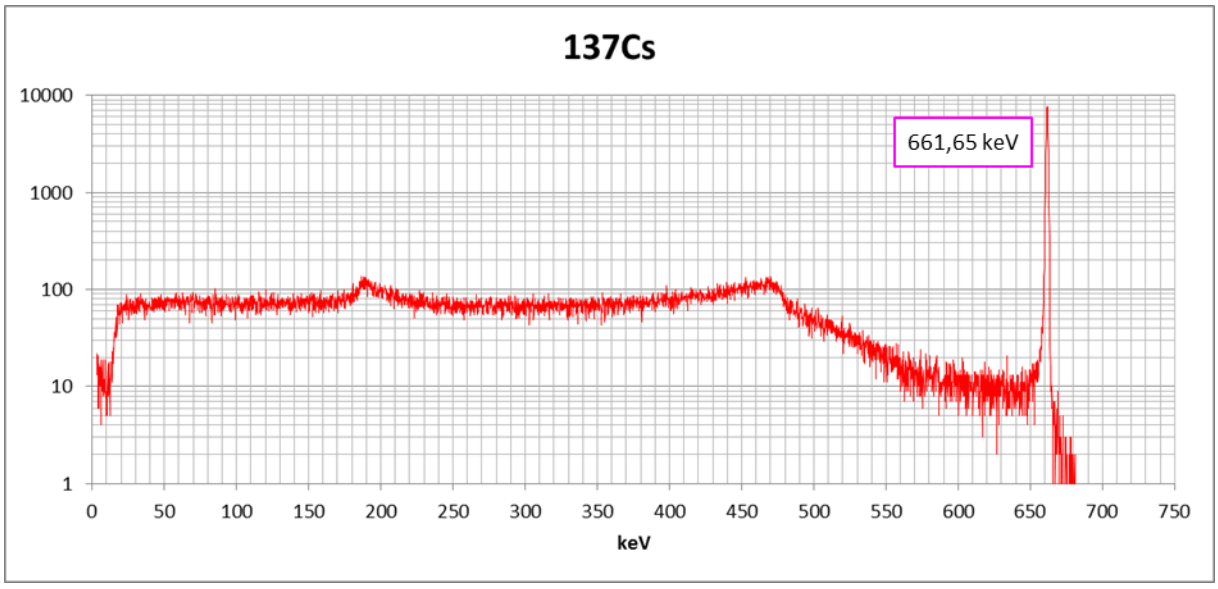
The interresting thing in this spectrum is the resolution of the 511 and 1274keV peaks. For the latter the resolution is 1.95keV$_{FWHM}$ (about the same as for ^{60}Co) but for the former, the resolution is 2,74keV$_{FWHM}$ (in this energy region, it should be about 1,3keV$_{FWHM}$).

In fact, this is not a matter of resolution, but of physics. The "511keV" γ energy is slightly shifted by the longitudinal momentum p_L the electron/β+ couple had at the moment of annihilation. The energy shift ΔE affecting both photons is (the sign is different for each photon):

$$\Delta E = \pm \frac{c \cdot p_L}{2}$$

This technique is called Doppler Broadening Spectroscopy (DSB) and is used to study microscopic defects orbitals configuration in solids.

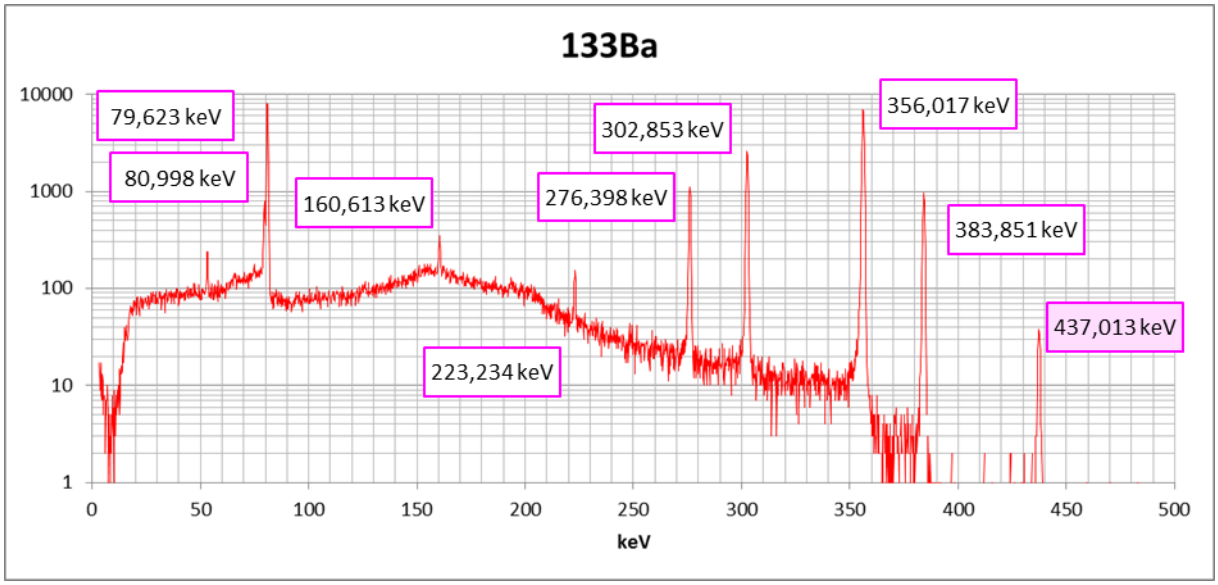
---===ooOoo===---



The resolution on the ^{137}Cs peak is 1.32keV$_{FWHM}$.

---===ooOoo===---

J-M. Fontbonne, C. Fontbonne, **LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, Caen, France**



^{133}Ba has got a lot of peaks. Direct decrease by 437keV is impossible but this peak is the sum of cascaded γ events as can be seen in the decay drawing. One can mention that the low energy resolution is about 0,50keV$_{FWHM}$ which is near the intrinsic resolution of our HPGe detector.

---===ooOoo===---

J-M. Fontbonne, C. Fontbonne, **LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, Caen, France**

3.3. Linearity

The linearity of the data acquisition system is an important factor for extended ranges applications. The graphs below show the calibration line for the peaks of previous reference sources and the residue between the straight line and the experimental points, showing energy errors under ±400eV.

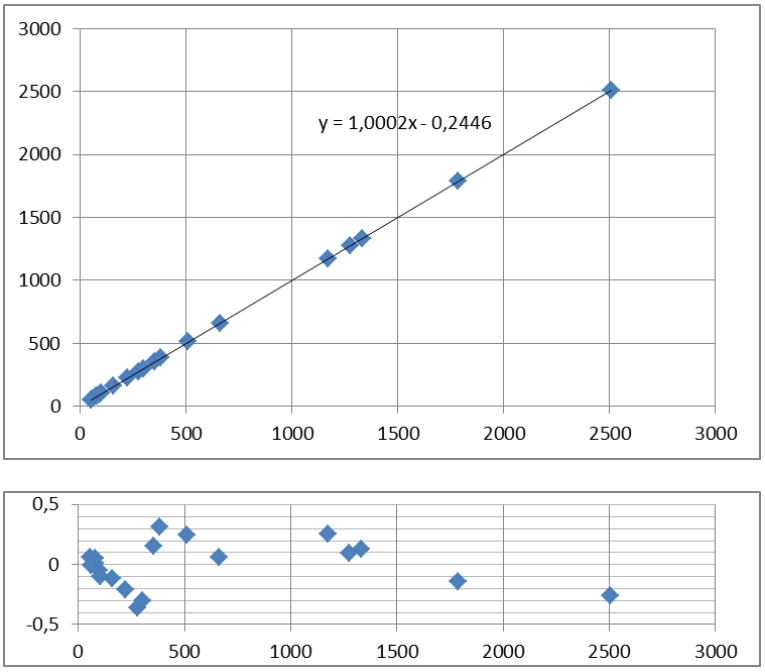


Fig. 2: linear calibration of the system (top) and calibration error (bottom) as a function of energy.

3.4. Peaks Resolution

The spectra database above is a good way to plot the resolution evolution versus energy in the HPGe detector. One would obtain something like that:

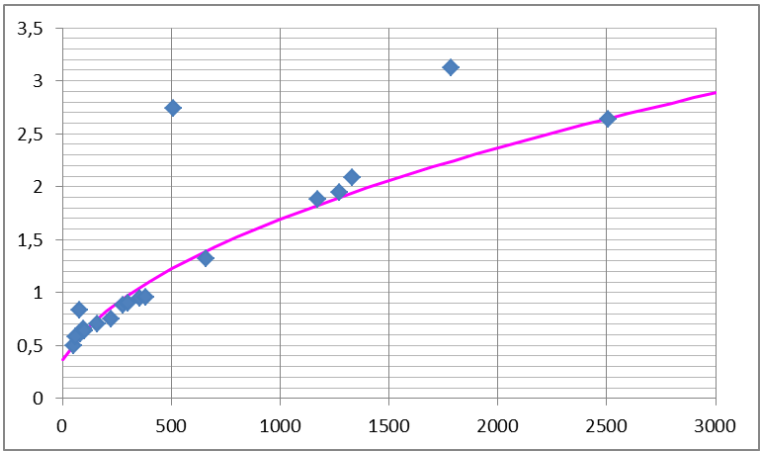


Fig. 3: resolution of the system (FWHM) as a function of γ energy.

The straight magenta line is a fit of experimental data (except 511keV ray and sum peak of ^{22}Na source) of the form:

$$\sigma_{\mathrm{FWHM}} = \sqrt{0.364\mathrm{keV}^2 + 2.5\cdot 10^{-3}\cdot E_{\mathrm{keV}}}$$

The constant term of this equation is the intrinsic electronics noise (charge sensitive preamplifier and shaper), here $0{,}364\mathrm{keV}_{\mathrm{FWHM}}$. As the energy imparted to create an electron/hole pair, ε, in Ge is 2,95eV, one can conclude that electronic noise is about $53\mathrm{pairs}_{\mathrm{RMS}}$.

The energy varying term comes from random variations on the electrons/holes produced by the incident photon. In fact, Fano demonstrated that energy deposition in a HPGe detector is not a perfect random poissonian process. If it were, this term would write: $2.35.(\varepsilon.E)^{½}$ (ε and E expressed in keV). Introducing the so called Fano factor F, the peak resolution now writes:

$$\sigma_{\mathrm{FWHM}} = \sqrt{\sigma_{elec}{}^2 + 2.35^2 F\cdot\varepsilon\cdot E_{\mathrm{keV}}}$$

Identifying the two equations, one can conclude that our Fano factor is about 0.15, a little bit higher than literature.

3.5. Pileup detection incidence on spectroscopy

FASTER doesn't perform pile-up rejection. It "only" makes pile-up detection (when it's possible). Pile-up detection flag informs the user of the quality of its signal. If set to 1, the pulse was piled-up. If set to 0, the pulse was probably pile-up free. This is a convenient way to acquire clean spectra as shown on Fig. 4. This procedure reduced 10 times the high energy background of this ^{22}Na source. Clearly, some piled-up events were not detected.

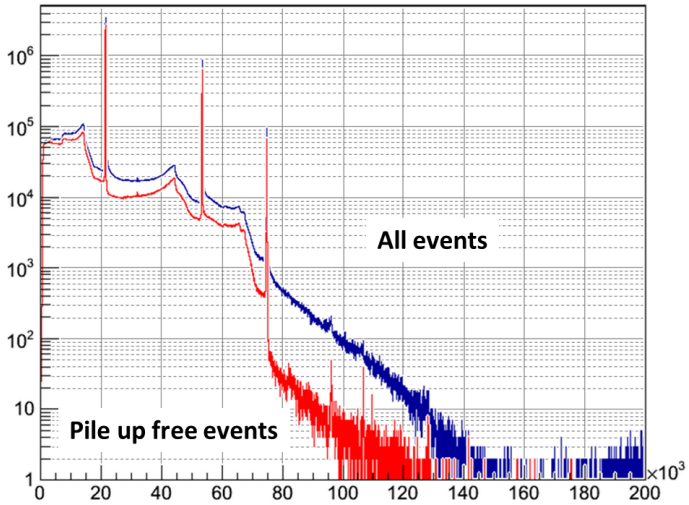


Fig. 4: pile-up detection using FASTER

Associated with FASTER counting capacities, this approach leads to pretty good dead time corrections. In fact pulse counting is performed by the event counter on the fast out trigger line. The pulse shaping on this line inhibits pulse detection for about 200ns. If a second pulse starts in these 200ns, it won't be detected (leading to undetected pile-up event). But if the pulse starts a few nanoseconds after these 200ns, it will be properly counted (as it should).

So, if you use the "pile-up free" events spectrum and you correct the count rate by the ratio of the detected event counter to the number of "pile-up free" events, you will have a good estimation of your experiment true count rate for each peak.

3.6. Base-Line Restorer incidence on spectroscopy

Base-line restoration if often neglected by users. In fact signal shaping theory is based on first order analysis of detectors and preamplifier noise spectral density. Obviously, electromagnetic compatibility (EMC) is supposed perfect which is rarely the case. In order to cope with base-line fluctuations, one needs a base-line restorer.

As we formerly saw, the uncertainty on 662keV cesium peak is on the order of $1.95keV_{FWHM}$. If one disconnects BLR correction the uncertainty increases up to $2.35keV_{FWHM}$. Obviously, this figure precisely depends on local EMC shielding but it illustrates how fast the resolution can degrades.

The cutoff frequency of the BLR follower is of some importance. As previously mentioned, a low cutoff frequency leads to optimal noise performances, here, $1,95keV_{FWHM}$.

With a high cutoff frequency, base-line fluctuations are corrected faster at the expense of an increase of noise. In our experiment, selecting high cutoff frequency led to a 2.05keV$_{FWHM}$ uncertainty.

4. Conclusions

Spectroscopy is the basis of nuclear instrumentation. The fully integrated CR-RC4 shaper, if not being the best shaping technique, provides good result on almost all nuclear detectors. Combined to its adjusting simplicity, it's a good way to approach optimal instruments performances.

J-M. Fontbonne, C. Fontbonne, **LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, Caen, France**