# γ-ray measurements and neutron sensitivity in a fusion environment

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# $\gamma$-ray measurements and neutron sensitivity in a fusion environment

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**Abstract.** A system based on a $LaBr_3$(Ce) scintillator and digital data acquisition is discussed in view of $\gamma$-ray spectroscopy measurements on a fusion burning plasma. High energy resolution and high rate capability of the system are demonstrated in laboratory tests and in dedicated experiments at nuclear accelerators. Preliminary results on sensitivity of the detector to 14 MeV neutrons are presented.

**Keywords:** gamma ray, spectroscopy, scintillator, neutron, burning plasma, nuclear fusion.
**PACS:** 29.30.Kv, 52.70.La, 52.55.Pi

## INTRODUCTION

$\gamma$-ray spectroscopy is being proposed as a diagnostic for fast ions on burning plasmas [1]. Information, both at a qualitative and quantitative level, can be retrieved from the measured spectrum by modeling of the nuclear emission processes and fit to measured data [2,3]. When compared to other fast ion diagnostics, $\gamma$-ray measurements provide several operational advantages, due to the inherently passive nature of the observation. Among these, the possibility to place the detector far from the fusion device avoids all technical constraints related to probes exposed to the severe heat fluxes in proximity of a burning plasma and that are expected for many fast ion diagnostics for energetic ions used on present day devices.

A $\gamma$-ray measurement on a burning plasma machine however needs to meet three important requirements: high resolution, high rate capability and low sensitivity to neutron background.

In recent years a new scintillator, $LaBr_3$(Ce), has been developed and used in a number of nuclear physics oriented experiments [4]. Its fast scintillation properties

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(≈40 ns) and high light yield makes it an interesting candidate also for γ-ray spectroscopy observations on a burning plasma.

In this work we discuss a system based on a $LaBr_3$(Ce) detector and present results of measurements in the laboratory and at nuclear accelerators. Preliminary indications on the scintillator sensitivity to 14 MeV neutrons are finally illustrated.

## DIGITIZATION AND ENERGY RESOLUTION

Due to its fast scintillation properties, $LaBr_3$(Ce) is a promising candidate for γ-ray spectroscopy measurements at high rates. In a standard nuclear spectroscopy system, however, the overall acquisition time is determined by the combination of the scintillation time and the time $\tau$ required to process each individual pulse coming out of the photo multiplier tube (PMT) connected to the scintillator. In most experiments, pulse processing is performed with a combination of an analog pre-amplifier and amplifier that provide an optimized signal/noise (S/N) ratio. The drawback of such solution is that $\tau \approx 1$ μs, which rules out a conventional analog shaping system for high rate (≈ 1 MHz) applications.

The shaping time $\tau$ can be significantly reduced through fast digitization of the PMT signal output. The PMT signal is fed into a fast non-shaping preamplifier with x5 gain. Digitization is done with a data acquisition based on the ATCA platform [5,6] and a sampling frequency up to 400 MSPS at a nominal 14 bit resolution. In order to reduce noise pick-up, a threshold on the signal is set. Each data segment corresponding to a digitized pulse consists of 128 samples. The first 30 points represent the baseline level before the recorded pulse. The remaining points contain the actual digitized pulse. A time-stamp is associated to each digitized event to allow for time resolved data analysis. In this way, the overall processing time is reduced to the intrinsic decay time of the scintillation light (≈ 40 ns).

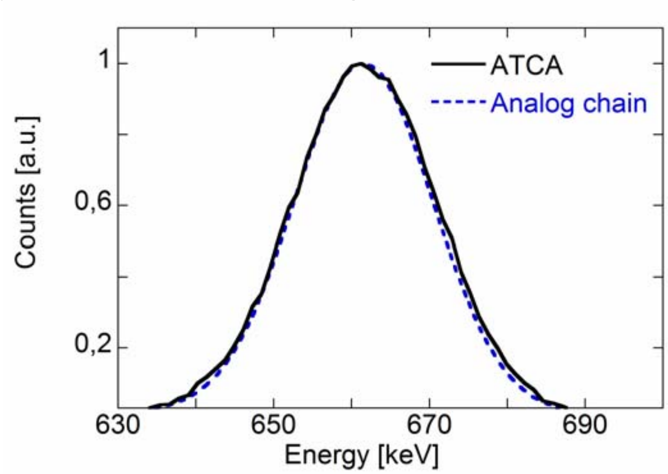


**FIGURE 1.** 662 keV emission peak from a $^{137}$Cs source measured in the laboratory with a $LaBr_3$(Ce) crystal using a standard analog shaping chain and the ATCA digitizer system.

The absence of a shaping stage in the DAQ chain implies a somewhat worse S/N ratio, which can affect the energy resolution of the recorded spectra. To preserve energy resolution, a spectrum reconstruction algorithm based on pulse fitting has been developed [5]. The recorded waveforms are analyzed off-line: a parameterized pulse shape is fitted to each event; finally, a pulse height spectrum of the fitted waveforms is produced. Figure 1 shows a comparison of a $^{137}$Cs peak measured in the laboratory using a $LaBr_3$(Ce) scintillator and either a conventional analog shaping chain or the ATCA digitizer system described above. The energy resolution is essentially identical in the two cases.

## HIGH RATE GAMMA RAY SPECTROSCOPY

On a high power fusion burning plasma event rates in excess of 1 MHz can be expected from γ–ray emitting reactions. Capability to perform γ-ray spectroscopy at high rates is required and can be tested today in experiments at nuclear accelerators.

High rate experiments were performed at the Tandem Van Der Graf accelerator of the Nuclear Institute "Horia Hulubei" in Bucharest [7]. A beam of protons accelerated at an energy of 10 MeV was sent on a thick aluminum target. The $LaBr_3$(Ce) detector coupled to the ATCA digitizer system was used for the measurements. The PMT was equipped with an active voltage divider to minimize gain drifts induced by high signal currents [8]. Gamma rays from the nuclear reactions $^{27}$Al(p,nγ)$^{27}$Si and $^{27}$Al(p,αγ)$^{24}$Mg were detected in experiments at different counting rates. The latter were varied by changing either the accelerator current or the detector position relative to the interaction chamber. In this way, counting rates ranging from 50 kHz up to about 5 MHz were achieved.

Figure 2 (a) shows the measured spectrum at a counting rate of 80 kHz. Several emission peaks can be identified and can be ascribed to decays from excited states of $^{27}$Si or $^{24}$Mg. The observed energy resolution at $E_\gamma$=3 MeV is about 2 % and is close to the optimal expected value.

At higher counting rates, pile up events started to be of relevance and were observed in the measured digitized waveforms. For this reason, the algorithm for off-line spectrum reconstruction was upgraded with a pile up rejection routine, which was used to discard waveforms showing superposition of more than one pulse.

Figure 2 (b) shows the result of a measurement at a counting rate of 1.3 MHz to be compared to the spectrum of figure 2 (a). All γ-ray peaks due to proton interaction on $^{27}$Al observed at lower counting rates are still well identified despite a higher background level due to enhanced environmental radiation near the accelerator interaction chamber at increased counting rates.

No degradation of the energy resolution is observed at 1.3 MHz. For instance, the energy resolution at the $E_\gamma$= 3 MeV peak is 2% as it was found at lower counting rates. The result of figure 2 therefore demonstrates high resolution γ ray spectroscopy performed with the combination of a $LaBr_3$(Ce) detector, an ATCA digitizer system and off-line spectrum reconstruction algorithms based on pulse fitting.

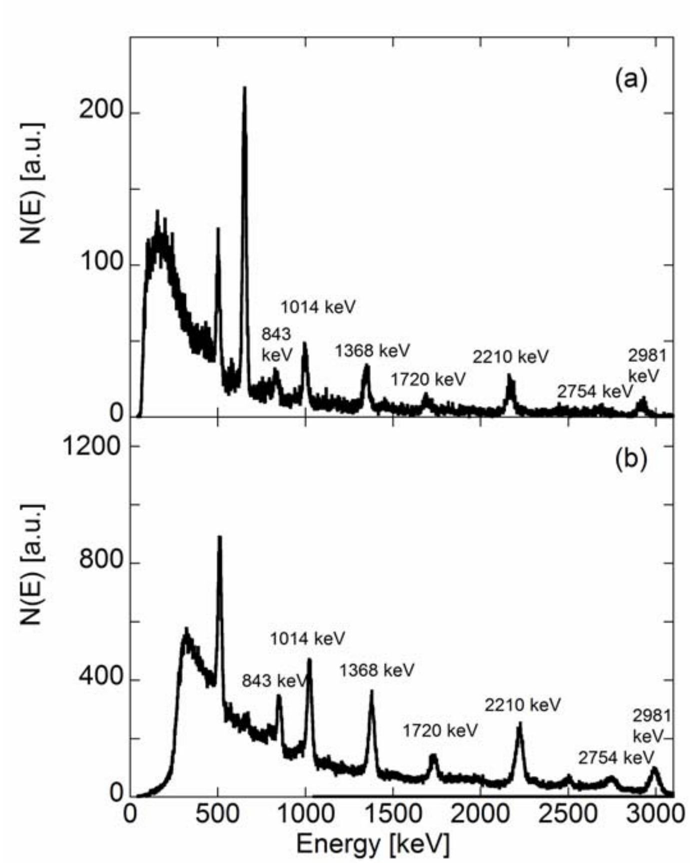


**FIGURE 2.** Measured spectra from the p+$^{27}$Al reaction at 80 kHz (a) and 1.3 MHz (b) counting rates. In figure (a), the peak at $E_\gamma$=0.66 MeV comes from a $^{137}$Cs source used for energy calibration. This peak is barely distinguishable in figure (b) due to higher background level.

## NEUTRON SENSITIVITY

Neutron emission represents an unavoidable background source for γ-ray spectroscopy measurements in a fusion environment. Although several techniques to reduce neutron background have been studied in relation to γ ray measurements in vicinity of a tokamak [9], low sensitivity of the detector to neutron emission is highly desirable.

A preliminary assessment of the $LaBr_3$(Ce) neutron sensitivity is provided by Figure 2 (b). The $^{27}$Al(p,nγ)$^{27}$Si reaction is primarily a source of neutrons, which represented an unavoidable background during the measurements at the Tandem accelerator. However, no clear structure that could be ascribed to neutron interaction with the $LaBr_3$(Ce) crystal is observed in the spectrum.

Dedicated tests to investigate the $LaBr_3$(Ce) response to neutrons were performed at the Frascati Neutron Generator [10]. The detector was irradiated with $E_n$=14 MeV neutrons produced by interaction of a 100 keV deuteron beam on a target containing tritium. The resulting measured spectrum is shown in figure 3. Several peaks due to neutron interaction with the crystal emerge on a decaying exponential background. A detailed data analysis is still in progress. Preliminary results suggest that inelastic neutron scattering on La and Br isotopes might be the dominant process. As the interaction cross section changes significantly as a function of the neutron energy, modifications to the response function are to be expected depending on the energy spectrum of the neutron source. A more detailed analysis of the measurements is necessary to single out the different processes responsible for the observed peaks. The results will be of significance for γ-ray spectroscopy measurements on burning plasmas including those to be used in fusion-fission hybrid systems.

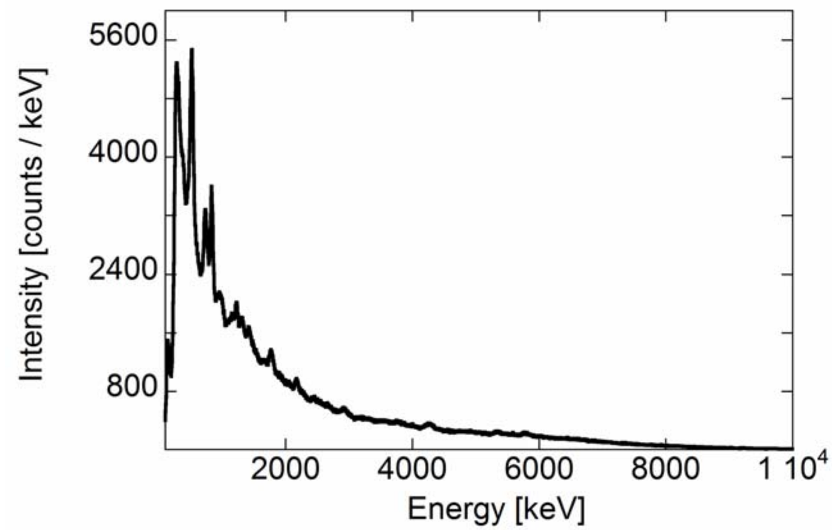


**FIGURE 3.** Pulse height spectrum resulting from irradiation of a $LaBr_3$(Ce) scintillator with 14 MeV neutrons at the Frascati Neutron Generator. Several peaks due to neutron interaction with the crystal emerge on an exponentially decaying background.

## CONCLUSION

A solution based on a $LaBr_3$(Ce) scintillator for γ-ray spectroscopy measurements in a fusion environment has been presented. Fast digitization was found to be the key for γ-ray spectroscopy measurements in the MHz range, together with ad hoc designed hardware and software solutions. Experiments conducted at a Tandem accelerator demonstrated the system high rate capability, without appreciable degradation of the energy resolution. An assessment of the detector sensitivity to 14 MeV neutron background was performed. A preliminary analysis of the measured spectrum showed spectral peaks that can be ascribed to inelastic neutron scattering on La and Br nuclei.

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