Timing Characterization of the NEDA Detector

A. Raggio¹, G. Jaworski², V. Modamio³, J.J. Valiente-Dobón², A. Goasduff¹, ⁵, B. Saygı², ⁶

¹ Dipartimento di Fisica e Astronomia, Università di Padova, Padova, Italy.
² INFN, Laboratori Nazionali di Legnaro, Legnaro (Padova), Italy.
³ Univ. of Oslo, Norway. ⁵ INFN, Sezione di Padova, Padova, Italy. ⁶ Ege University, Izmir, Turkey.

INTRODUCTION

One of the main purposes of contemporary nuclear physics is the study of nuclei far from the valley of β stability. Neutron-deficient exotic nuclei can be experimentally produced by fusion-evaporation reactions. However, in order to identify them among other channels, neutron detector arrays with high efficiency and high neutron-γ discrimination capabilities are a must. In 2007 a new project to design and construct a neutron detector array, named NEDA, started, and after several tests and optimizations the single detector reached its final form. In 2015, the definitive NEDA detectors production started [1]. NEDA will be coupled for the first time with the γ-tracking array AGATA [2] at GANIL for a physics campaign in 2018 [3]. In this report the timing resolution of a single NEDA detector is discussed.

EXPERIMENTAL SET-UP

NEDA will make use of digital electronics and digital signal processing [4]. In order to compare analog and digital time resolution and to characterize the overall timing performance of the detector a test was performed. A $^{60}$Co γ source was used for the test, employing a commercial 1” × 1” BaF$_2$ fast detector as a time reference.

As shown in Fig. 1 the two detectors, BaF$_2$ and NEDA, were placed perpendicularly to each other at a distance of 50 mm and 170 mm from the $^{60}$Co source, respectively. In order to minimize the scattering of γ rays from one detector to the other a lead shield was placed between them. The anode signals from the two detectors were sent to two channels of a LeCroy N428A linear fan-in/fan-out unit, then the output signals were connected to a sampling ADC in order to have the digitized waveforms for digital analysis, and to an analog CFD units of type Phillips 715 to perform the analog timing, that serves as the trigger for digitizer as well. A LeCroy 465 module was used to select the coincidences between both detectors; this signal, time aligned with the NEDA one, was sent as start to an Ortec 566 TAC unit, while for the stop, a delayed BaF$_2$ CFD signal was used. Finally the signals from the TAC module were digitized. The module used to digitize the anode waveforms was a sampling ADC of model Struck SIS3350, a VME unit with four channels, each with a sampling frequency of 500 MS/s and a resolution of 12 bits. Similarly the TAC signal was digitized with a Struck SIS3302 sampling ADC (single width 6U VME, 8 channels, 100 MS/s, 16 bit).

DIGITAL TIMING ALGORITHM

The digitized signals of the two detectors were processed using a CFD algorithm [5], as shown in Fig. 2: a Zero-Crossing signal $ZC$ (red pulse) was created by summing the original waveform $S$ (sampled black pulse) attenuated by a factor $\chi$ (blue pulse) and its inverted signal delayed by an integer number of samples $\Delta$ (green pulse). The attenuation factor $\chi$ and the delay $\Delta$ were optimized to achieve the best timing resolution. The Zero-Crossing point was then obtained using the first three negative and preceding three positive samples employing a cubic spline interpolation with boundary continuity condition up to the second derivative.

![Fig. 1. Experimental set-up for timing characterization. SIS3350 and SIS3302 are the digitizer used for the experiment.](image1)

![Fig. 2. CFD algorithm for a digitized NEDA signal. Four different waveforms are represented: the original detector signal (black), the inverted and delayed signal (green), the fractioned signal (blue) and finally the zero-crossing signal (red).](image2)
TIMING COMPARISON

An energy calibration was performed using the digitized signals from the NEDA detector with four different $\gamma$ sources (see Table 1). The Compton Edges of the $\gamma$-rays spectra from $^{22}$Na, $^{137}$Cs, $^{60}$Co, and the photopeak for the low-energy 59.5 keV line from a $^{241}$Am source were used.

Table 1. $\gamma$-ray sources used for calibration with photopeak (Ph) or Compton Edge (CE) characteristic energies.

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{241}$Am Ph</td>
<td>59.541</td>
</tr>
<tr>
<td>$^{22}$Na CE</td>
<td>1061.7</td>
</tr>
<tr>
<td>$^{137}$Cs CE</td>
<td>477.334</td>
</tr>
<tr>
<td>$^{60}$Co CE</td>
<td>963.419</td>
</tr>
</tbody>
</table>

Employing the energy calibration, the digital timing distribution for the BaF$_2$+NEDA system as a function of the energy was drawn in Fig. 3.

![Fig. 3. Digital timing as a function of energy for C$^2$ cubic spline interpolation. The Compton Edges of $^{60}$Co located around 1000 keV are visible.](image)

The CFD Zero-Crossing line was optimized to minimize the time dependence on the amplitude, so called time walk. To evaluate the detector timing capabilities, energy projections of 200 keV width on the Fig. 3 were used. The overlap among the digital and analog timing distributions of the whole data-set is displayed in Fig. 4.

As fitting function to these distributions a Gaussian with two exponential tail functions was used [6]:

$$f(x; \bar{x}, \sigma, k_L, k_R) =
\begin{cases}
    \frac{k_L^2}{e^{\frac{(x-\bar{x})^2}{2\sigma^2}} + k_L(x-\bar{x})} , & \text{for } \frac{x-\bar{x}}{\sigma} \leq -k_L, \\
    \frac{k_R^2}{e^{\frac{(x-\bar{x})^2}{2\sigma^2}} + k_R(x-\bar{x})} , & \text{for } -k_L < \frac{x-\bar{x}}{\sigma} \leq k_R, \\
    e^{-\frac{(x-\bar{x})^2}{2\sigma^2}} , & \text{for } k_R < \frac{x-\bar{x}}{\sigma}.
\end{cases}$$

The FWHM has been calculated as difference between the two edge point HWHM1 and HWHM2, estimated from the fit parameters:

$$\text{HWHM1} = \begin{cases}
    \bar{x} - \sigma \left( k_L - \frac{\ln(\frac{1}{2})}{k_L} \right), & \text{for } k_L < \ln(2)\sqrt{2}, \\
    \bar{x} - \sigma \ln(2)\sqrt{2}, & \text{for } k_L \geq \ln(2)\sqrt{2}.
\end{cases}$$

$$\text{HWHM2} = \begin{cases}
    \bar{x} + \sigma \left( k_R - \frac{\ln(\frac{1}{2})}{k_R} \right), & \text{for } k_R > \ln(2)\sqrt{2}, \\
    \bar{x} + \sigma \ln(2)\sqrt{2}, & \text{for } k_R \leq \ln(2)\sqrt{2}.
\end{cases}$$

![Fig. 4. Analogue and digital timing distributions normalized to the total area, over the whole energy spectrum. The horizontal lines represent the FWHM of the two distributions.](image)

With the FWHM of the distributions the timing performance was evaluated over different energy gates, for both analog and digital electronics. The results show excellent timing resolution, reaching even better performances for digital techniques.

SUMMARY

In this paper an initial analysis of the timing performance employing both analog and digital techniques of a single NEDA detector has been discussed. The detector is showing excellent timing performances, however to fully characterize it further tests and analysis are necessary.