Application Note AN6872
Energy and Timing characterization of two $CeBr_3$ detectors with a DT5730 digitizer and CoMPASS

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Abstract

The purpose of this document is to show a brief overview of the operation and to report Energy and Time of Flight (TOF) resolution results obtained with a 500MS/s, 14 bit digitizer Mod. CAEN DT5730 **[1]**, the CoMPASS software **[2]** and two $CeBr_3$ detectors faced in front of a ^{22}Na and ^{60}Co source at 180°. This geometric configuration allows to acquire only back to back events. The system optimization was made with the ^{22}Na source, and the resulting settings were applied to the ^{60}Co source to get the final measurement. Both energy and timing filters were applied to select correlated signal events.

Setup

Two $CeBr_3$ detectors are aligned at 180° in front of each other. The radioactive source is located in the middle of the two detectors at a distance of about 1 cm. The PMTs are powered by the CAEN power supply N1471 at 660 V.

The output of the PMTs is directly read by the DT5730 digitizer equipped with DPP-PSD firmware (revision 4.17_136.16), connected via USB to a PC running Windows 10 OS. The digitizer is read by the CoMPASS software (revision 1.1.0). A diagram of the acquisition setup is shown in Fig. **1**.

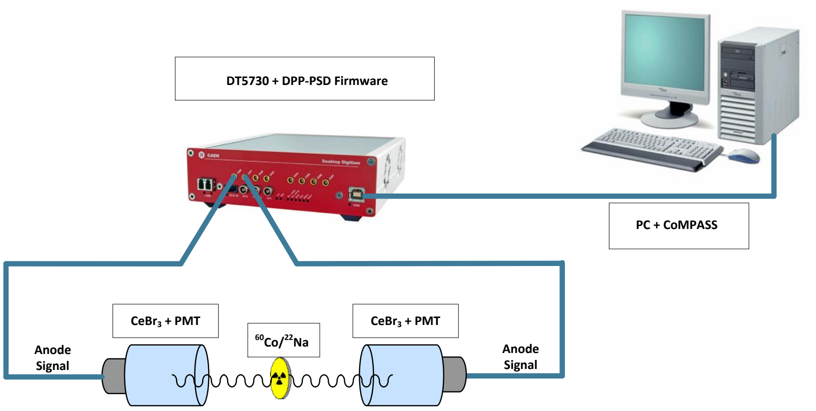

Fig. 1: Diagram of the hardware setup.

Measurement

Acquisition settings

The first part of the measurement is the correct setting of the digitizer parameters. It is important to correctly set all the settings to get a consistent result. The **"Waveform"** acquisition mode is useful to visualize on screen how the settings are related to the input pulse and to adjust them accordingly. To enable the Waveform mode select `Acquisition mode = Wave` in the *Acquisition* tab. Then press Start to start the acquisition.

Fig. **2** reports the input pulse (black) and the digital traces of interest for this application, the CFD (blue), and Gate (red). Note that the in case of DPP-PSD firmware there are two integration gates, called Long and Shot Gate, which are used for pulse shape discrimination (refer to **[2]** for more details). The Long Gate integration is used to report the energy spectrum of the pulse, while the Short Gate is not used in this application.

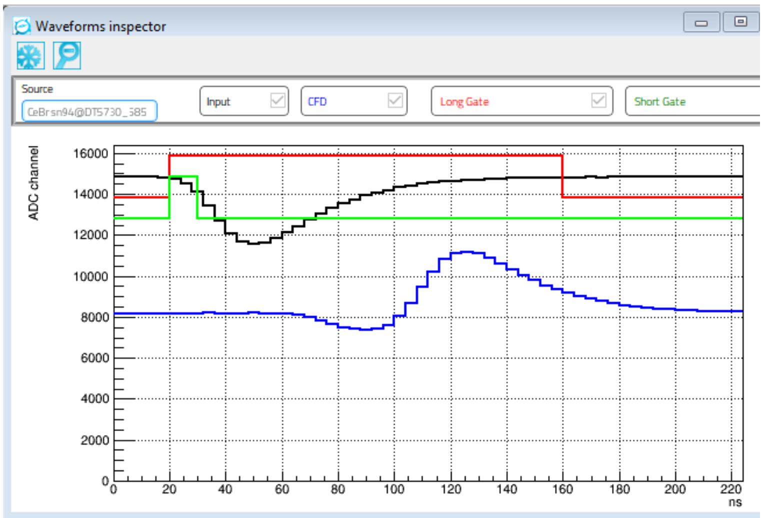

Fig. 2: Waveform visualization of the input (black), CFD (blue) and integration gate (red). The pre-trigger and gate offset must be correctly set to cover the full width of the pulse.

The following settings were used:

Setting	Value
Record length	224 ns
Pre trigger	80 ns
Ns Baseline	16 samples
DC Offset	10 %
Input dynamic	0.5 V_{pp}
Discrimination mode	CFD
Threshold	40 lsb
Trigger holdoff	200 ns
Cfd fraction	25 %
Energy coarse gain	10fC/LSB
Gate	140 ns
Gate offset	84 ns

Both the settings of energy and timing must be set correctly. The integration gate was set to cover the pulse width with respect to the trigger position. The internal discrimination has been set in CFD (constant fraction discrimination) mode to select events with a more precise timing resolution than leading edge mode (fixed threshold crossing). The preferred fraction value was set to 25 %.

To evaluate the correct CFD delay value we started using the formula: $d > (1-f) * RT$, where d is the delay, f is the fraction (25%) and RT is the input rise time of about 25 ns:

$$d > 19 \text{ ns}$$

Looking at the waveform (as in Fig. **2**), the optimal value was in the range [30,40] ns. Below 30 ns the zero crossing of the CFD is too squeezed, while after 40 ns the zero crossing of the CFD is too long. To choose the best value we performed the analysis described in the next section.

Once all the settings are correctly defined, switch to **"List"** acquisition mode to acquire the spectra, i.e. `Acquisition mode = List`. The use of "Waveform" mode is recommended in the configuration phase only.

CFD delay optimization

As described in the previous section the optimal CFD delay value is in the range of [30,40] ns. We varied the CFD delay with 2 ns step in that range and we looked for the best resolution of the time of flight (TOF) for events in the 512 keV peak of the ^{22}Na source. Those events are expected to be physically correlated, and the TOF resolution is used as a figure of merit for the choice of the CFD delay.

First of all the region of $\pm 2\sigma$ around the 512 keV peak is chosen as the "signal region". Events passing the energy cut are then time correlated and shown in the Tof plot of CoMPASS.

The ^{22}Na energy spectrum is reported in Fig. **3**, top left. As a first step we performed the energy calibration of the spectrum through the *"setup calibration"* tool. Three points were selected to get the calibration curve (linear interpolation). The resulting calibrated spectrum is reported in Fig. **3**, bottom left.

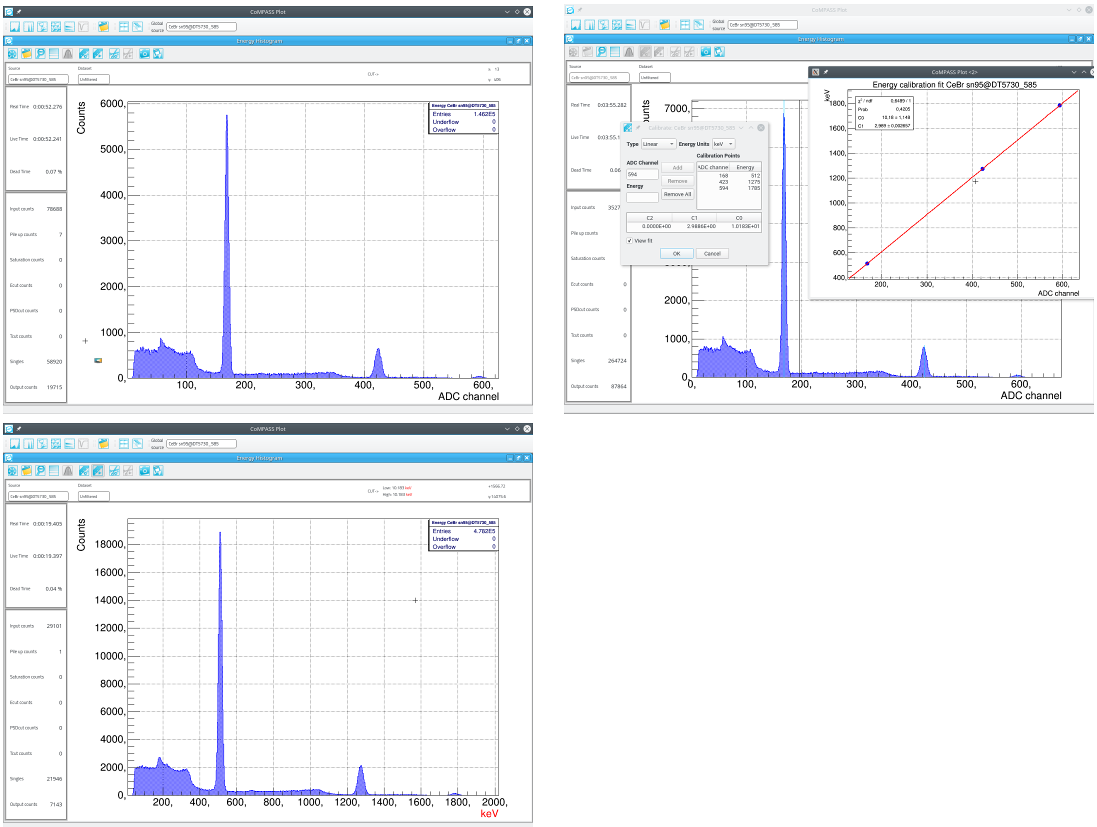

Fig. 3: Calibration procedure of a ^{22}Na gamma spectrum. Un-calibrated spectrum (ADC channels) is reported on the top left, the calibration points and the linear interpolation is reported on the top right (three points were chosen), while the calibrated spectrum (keV) is on the bottom left.

Fig. **4** reports a gaussian fit of the 512 keV peak of the ^{22}Na spectrum, where sigma $\approx$ 10 keV. We defined the *signal events* as those lying in $\pm 2\ \sigma$ under the 512 keV peak, i.e. [490,530] keV. Those energy limits can be set directly in the plot (through the *"Define cut"* button) or through the *"Rejection tab"* (in ADC channel only).

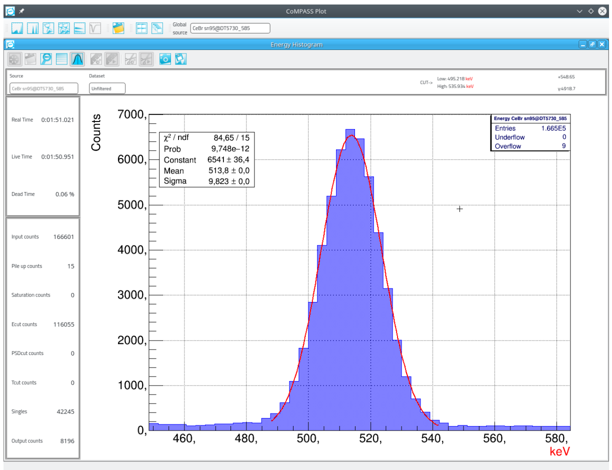

Fig. 4: Gaussian fit of the 512 keV peak of the ^{22}Na source.

A more precise fit can be done offline to consider the background contribution (modeled by a polynomial function). The resulting fit is reported in Fig. **5** where the sigma corresponds to 9.42 $\pm$ 0.02 keV. The FWHM is equal to 22.17 $\pm$ 0.06 keV, which corresponds to a resolution (defined as FWHM/Peak Mean) equal to **4.32** $\pm$ **0.01 %**.

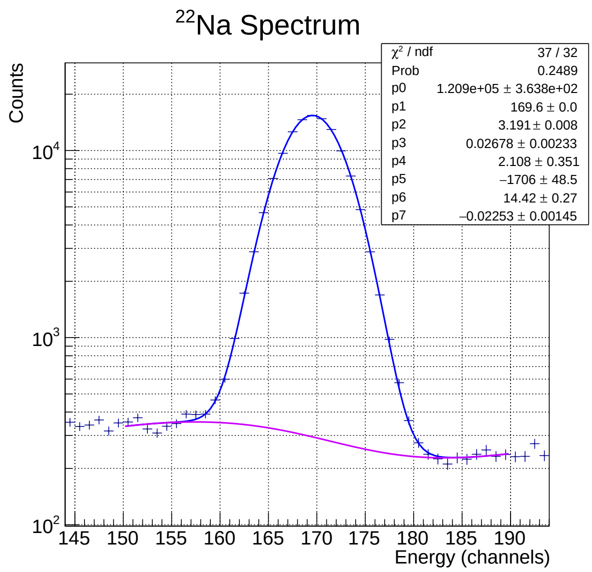

Fig. 5: Fit of the 512 keV peak of the ^{22}Na source with a Gaussian function for the peak and a polynomial function for the background.

To generate the TOF plot it is required to enable the time correlation through the *"Time selection"* tab of the GUI. The TOF plot becomes then available. Selected options are **"Paired AND"** and 0.1 µs of **"Correlation window"**. Events passing the energy and timing cuts are reported in the TOF spectrum.

A summary of the energy cut and TOF distribution is shown in Fig. **6**. On the left it is shown the TOF distribution of events passing both the energy and timing cuts. On the left there are shown the energy distributions of the two channels: in blue the events passing the cuts are reported and in gray the events before the filter.

A gaussian fit is applied to the TOF distribution (see Fig. **7**). The σ of the gaussian distribution is used as figure of merit to choose the best CFD delay. The selected *CFD delay of 38 ns* produces the smallest σ equal to about **247 ps**.

With the applied cuts, the OCR rate (refer to the Statistics tab) is about 75 Cps, and the total counts in 3 minutes of

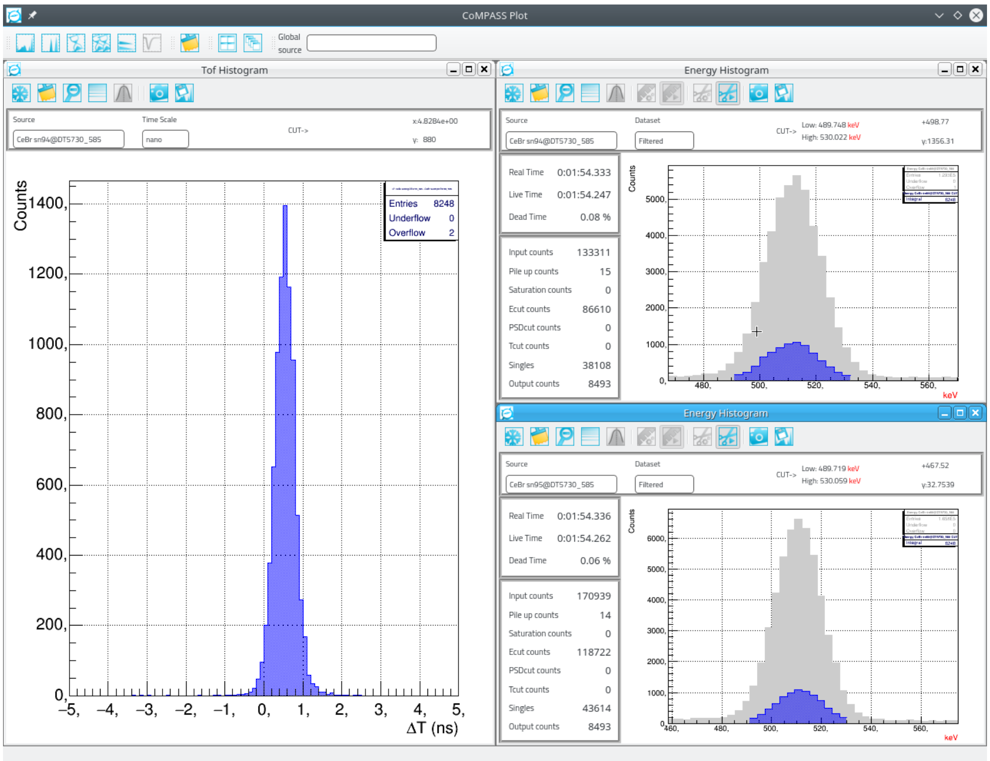

Fig. 6: Energy cut of $\pm 2\ \sigma$ of the 512 peak of the ^{22}Na source, applied on both channels (right plots). On the left the resulting TOF distribution.

acquisition corresponds to about 12k events for each CFD delay value.

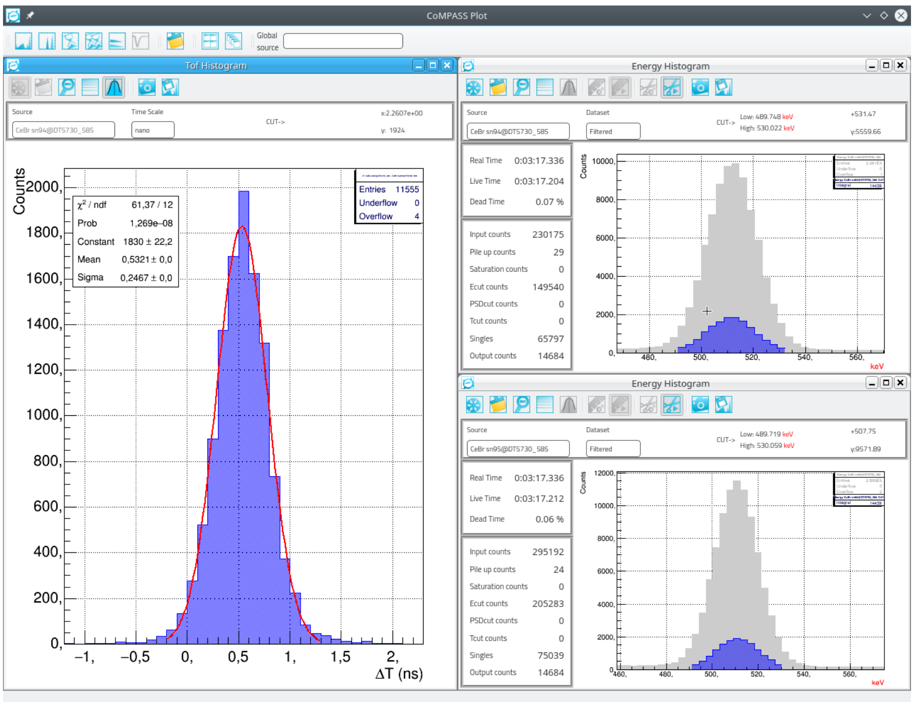

Fig. 7: Same plots as in Fig. **6** with a gaussian fit of the TOF distribution.

Measurement of a ^{60}Co source

The same settings obtained with the ^{22}Na source are then applied to the ^{60}Co source for consistency.

The two characteristic peaks of the ^{60}Co were fitted with a Gaussian function for the peak and polynomial function for the background. The two fits are reported in Fig. **8**.

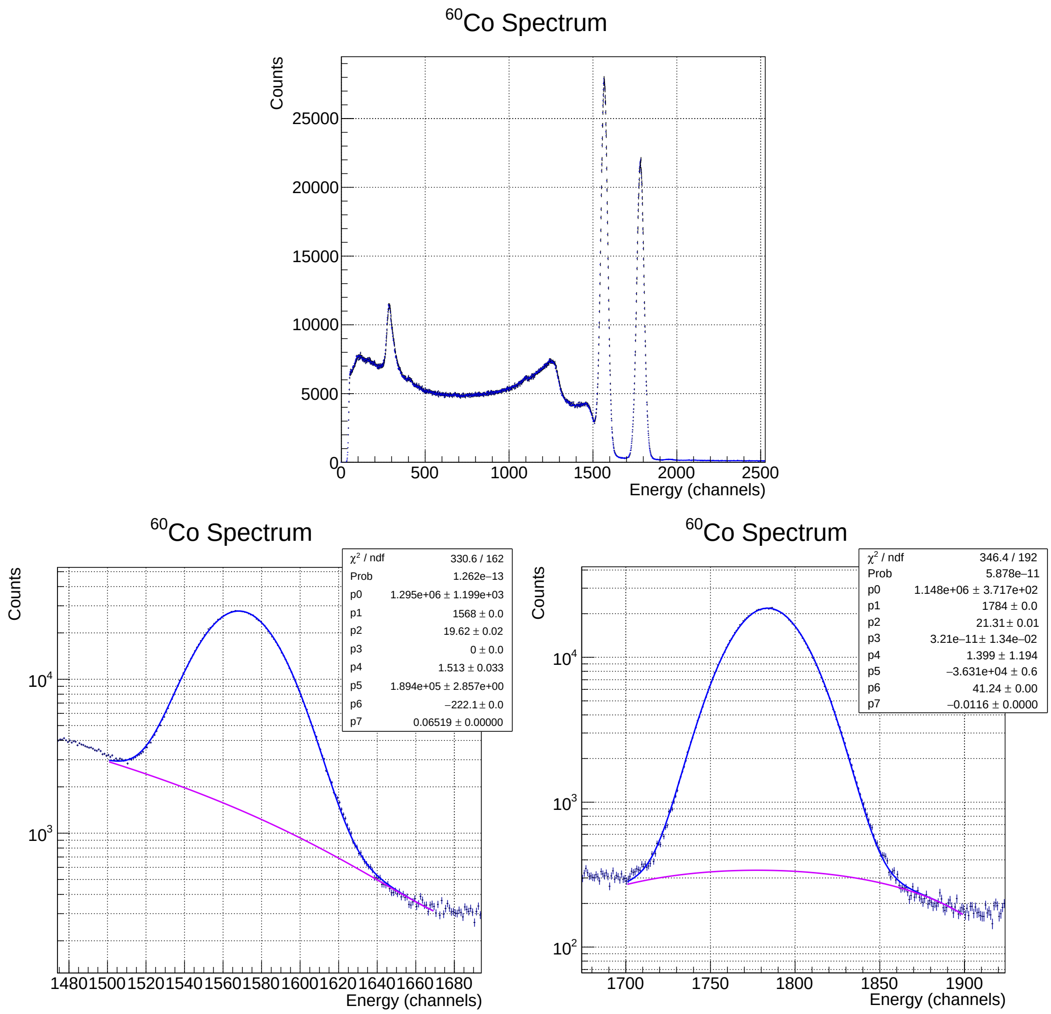

Fig. 8: Energy Spectrum of a ^{60}Co source (top). Fit of the 1173 keV (on the left) and of the 1332 keV (on the right) peak of the source with a Gaussian function for the peak and a polynomial function for the background.

For the 1173 keV peak the σ of the Gaussian is equal to 14.38 ± 0.01 keV, the FWHM = 33.85 ± 0.03 keV which corresponds to a resolution of 2.88 ± 0.01 %.

For the 1332 keV peak the σ of the Gaussian is equal to 15.62 ± 0.01 keV, the FWHM = 36.77 ± 0.03 keV which corresponds to a resolution of 2.76 ± 0.01 %.

Energy cuts for the time of flight selection were applied at about $\pm 2\ \sigma$ of the two peaks, thus resulting in the following ROIs: [1145,1200] keV and [1295,1370] keV.

The OCR rate is about 3 Cps; setting one hour measurement, the expected counts are about 11k events.

The resulting TOF distribution is reported in Fig. **9**. By using a gaussian function the σ is about **181 ps**, which corresponds to a FWHM of about **425 ps**.

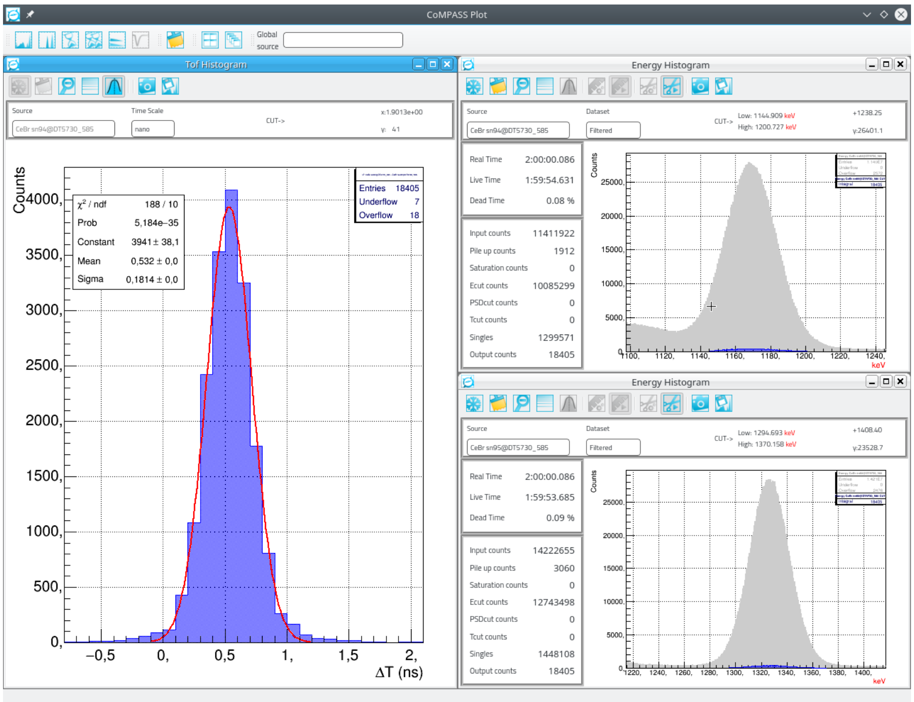

Fig. 9: Energy cut of about ±2 σ of the 1173 and 1332 peaks of the ^{60}Co source, applied on both channels (right plots). On the left the resulting TOF distribution with gaussian fit.

Results and conclusions

A measurement of Energy and Time of Flight resolution has been made with CAEN digitizer DT5730, the CoMPASS software and two $CeBr_3$ detectors faced in front of a ^{22}Na and ^{60}Co source. The energy resolution (defined as the ratio of FWHM and the peak energy) is about **4.3 %** for the 512 keV peak of the ^{22}Na source, **2.9 %** for the 1173 keV peak of the ^{60}Co source, and **2.8 %** for the 1332 keV peak of the ^{60}Co source. The TOF FWHM for ^{22}Na source is about **580 ps**, and for the ^{60}Co source is about **284 ps**.

References

[1] **UM3148 – DT5730 User Manual**.

[2] **UM5960 – CoMPASS User Manual**.

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