Forschungszentrum Jülich

Internal Report No. FZJ_2013_02893

Preliminary Investigation of a Waveform Analysis with the WASA and the ACQIRIS Readout Electronics.

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July 16, 2013

Abstract

The Group for the development of neutron and gamma detectors in the Central Institute of Engineering, Electronics and Analytics (ZEA-2) at Forschungszentrum Jülich (FZJ) is developing a fast Anger Camera prototype for improving the rejection of the gamma contamination during the detection of neutrons. The prototype is based on a scintillating plate for neutron capture and on the subsequent generation of scintillating light collected by a matrix of 4x4 vacuum Photomultipliers R268 by Hamamatsu. According to the impinging point position of the incoming neutrons the light is collected by different PMTs, and via dedicated algorithms the x and y coordinates can be calculated. In this note the WASA and ACQIRIS readout electronics are compared while performing a waveform analysis of the signals generated by using both an analogue pulse generator and an LED+PMT system. Different options of pre-amplifiers and amplifiers are considered, and the results are here presented and commented. At this stage of the prototype development, systematical studies were not performed while the scope of this work was only to validate the principle of operations by using both readout systems.

Contents

1 Introduction

An Anger prototype made of a 4x4 matrix of vacuum photomultipliers has been built at the ZEA-2 Institute in the FZJ. Two different options for the readout electronics were analyzed, the ACQIRIS DC282 [1] and the WASA [2] QCD electronics.

In this paper the proof of principle to perform a waveform analysis with both systems is presented, without, at the moment, further investigating the systematical uncertainty involved. In combination with an offline analysis [3] to disentangle the contamination of gammas from neutrons, the waveform analysis should help to perform experiments with a larger purity of signals induced by neutrons.

The proposed prototype is expected to undergo a full series of measurements at the research reactor FRM-II [4] to show the capability to cope with the high demanding performance.

2 WASA Electronics: Description and Properties

For the WASA experiment a specific QDC card was developed . The design of the electronics comprises a fast signal and data processing by usage of modern technologies like field-programmable gate arrays (FPGAs).

A detailed description of the electronics can be found in [2]. Here we address only its main features: the front-end, Fig. 1, is equipped with LEMO 50 Ohm connectors to handle up to 16 single-ended signals. Each FPGA handles four

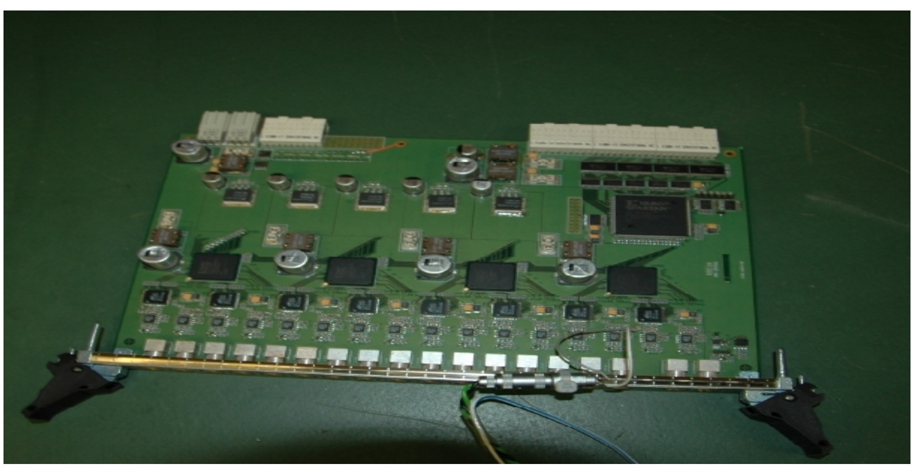

Figure 1: QDC module of the WASA electronics with the sixteen 50 Ohm Lemo connectors for the input signals. Visible at the front-end side (on the right) is the ad-hoc made connection to the ADC to test the processing of differential signals.

input channels and stores in a buffer the values provided by the individual ADCs, which can sample their corresponding signal at a rate of either 160 MHz (every 6.25 ns) or 80 MHz. The data acquisition can be configured to store either the entire waveform in a selectable gate window (up to 6.4 μs) or its peaking amplitude. A pre-(after-)window for the DAQ can be set to up ± 6.4 μs.

In this work the WASA electronics has been used in the so-called fast mode (160 MHz sampling rate). In this mode the signal is initially processed by the internal differential amplifier AD8132, and then sampled by the 12 bit ADC MAX1213 using only 11 bits. Each FPGA handles four channels, while in the the main FPGA register several cuts can be set to select events in specific amplitude and time windows. The setting of the FPGA is performed via API functions provided by the driver developers.

3 Analysis with an analogue Voltage Pulse Generator

3.1 Test-Bench Description

The characterization measurements of the readout electronics were performed at the laboratories in ZEA-2. The typical setup of the test-bench is shown in Fig. 2. No generator of tailed pulses with fast rise time (at the order of a few nanoseconds) was available; thus the analogue pulse generator Agilent 3325OA was used to generate voltage pulse with rise and fall time values set at 5 ns (the minimum allowed configuration).

To generate a current pulse an RC high-pass filter was used, maintaining

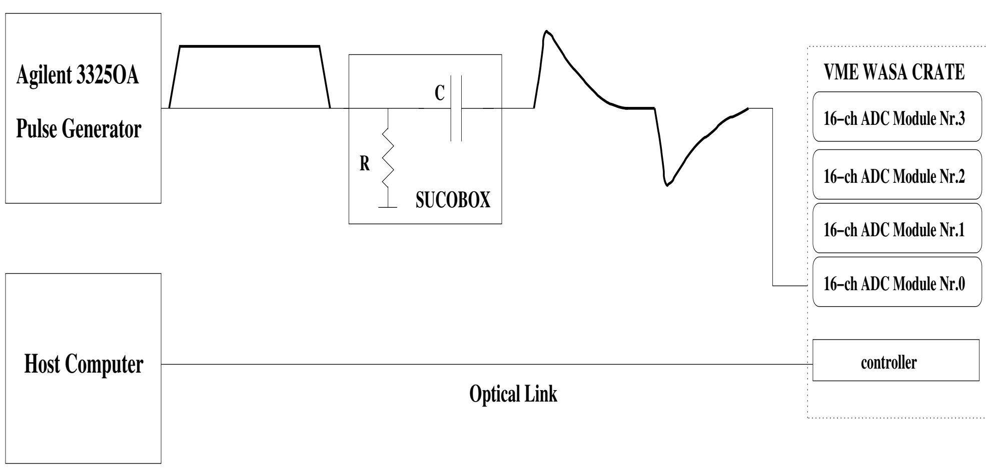

Figure 2: Test-bench setup used for the waveform analysis with the WASA readout system at FZJ. A similar experimental setup is used when using the ACQIRIS system: here network twisted cables are used for transmitting the data to the host computer.

a fast rise time as expected in a real experiment (large rise time values were observed to give rise to undershoots of the signal tail). The chosen filter, built up in a SUCOBOX, has the following parameters

$$\begin{aligned} R &= 50\ \Omega\ , \\ C &= 10\ nF\ , \end{aligned} \tag{1}$$

and generates two pulses with opposite polarity (corresponding to the rising or falling edge of the voltage pulse) with characteristic decay time of $\tau_c = 500\ ns$. The distance between the two pulses is given by the width of the incoming voltage pulse. The readout systems were properly configured to sample only one of the two peaks generated by the RC filter.

Using the same experimental configuration the signal was injected through a Lemo cable with 50 Ω impedance alternatively in one of the 16 input channels of the investigated WASA board, and in one of the four DC282 ACQIRIS channels (set to 50 Ohm input impedence), and the sampled waveforms were shipped to an external computer and there recorded for a later offline analysis. The approximately 6 m long 50 Ω Lemo cable used resulted in a signal (as measured at the oscilloscope) attenuation of a factor 0.58 using the amplitude of the output voltage set to 20 mV. This value is then used during the entire scan to rescale all the remaining amplitude values used. Note that this measurement at the scope could be quite un-precise, and thus might be affected by a strong systematical bias.

3.2 Measurements with the WASA System

To measure the ADC resolution of the WASA system a linear scan in the input voltage was performed. The results of a typical measurement is presented in Fig. 3 (here shown for the input voltage amplitude of 1900 mV).

In the upper panels it is shown the effect of the pedestal calculation and its subtraction to the data in the waveform analysis. The acquisition system (and with ACQIRIS as well) allows to record also a certain amount of data accumulated before the trigger for the acquisition is generated. In this example, for each waveform event from the initial 100 points (corresponding to $100 \cdot 6.25 = 625$ ns) the mean value and RMS are calculated and saved in the corresponding pedestal and noise histograms, shown in the middle panels.

For each event the calculated pedestal is subtracted to the waveform sampling data bringing, as expected, the baseline to zero, as visible in the right upper panel. Note the absence of undershoot in the signal tail region within this experimental configuration.

The test-bench plus readout system has a low noise, well below one ADC unit.

In principle, the deposited charge can be calculated out of the waveform integral (after pedestal subtraction). Unfortunately at this stage the ADC resolution is not known yet, and should be extracted out of the data. The measurement to calculate the ADC resolution (mV/ADC) is presented in the next subsection.

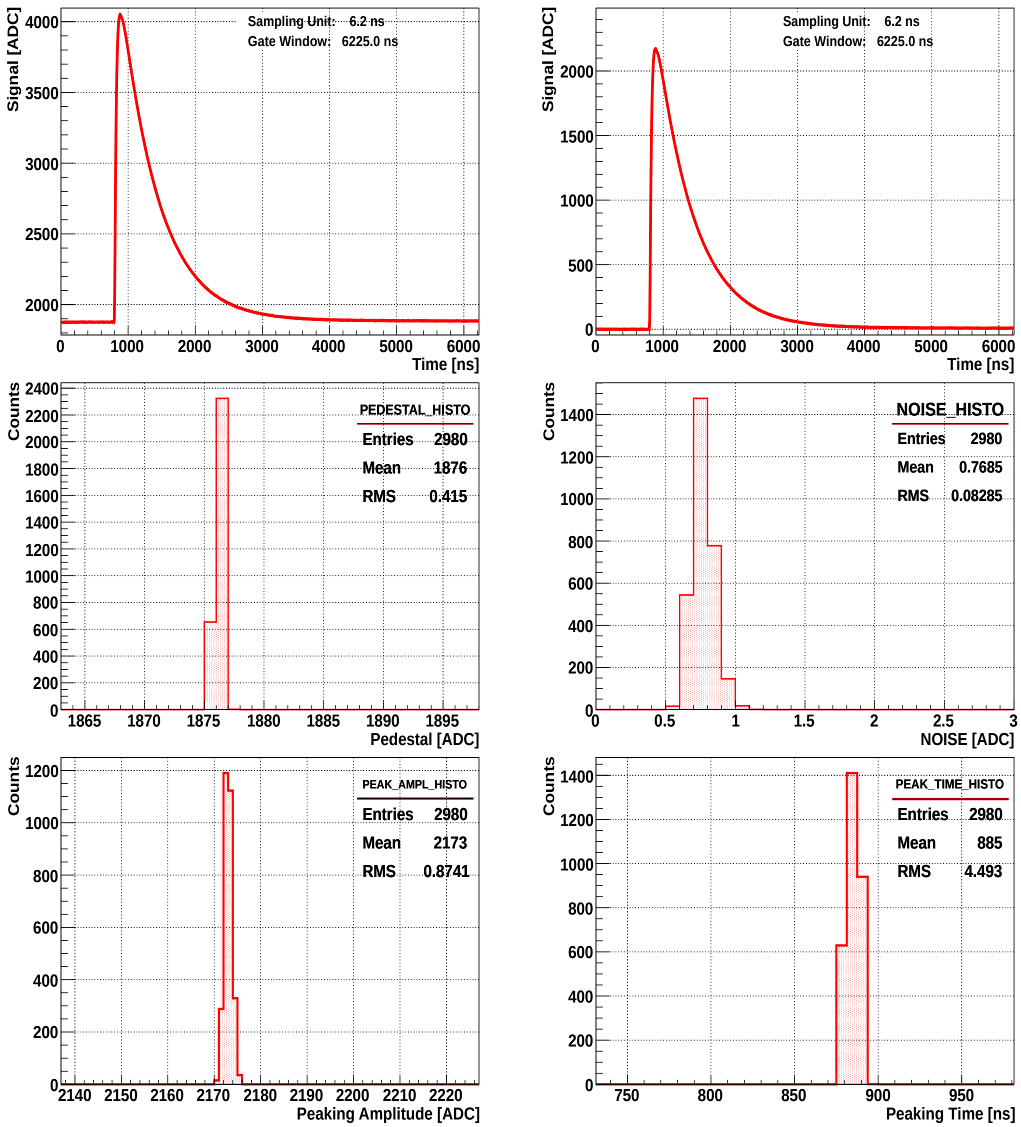

Figure 3: Typical histograms obtained during the waveform analysis with the WASA electronics. These examples were obtained with 1900 mV voltage amplitude provided by the pulse generator.

3.3 Linearity of the WASA system

A linear scan is performed, injecting into the WASA system waveforms with different values of the input voltage pulse amplitude, as shown in the Tab. 1.

The above data are presented in Fig. 4. A linear function is fitted to the

WASA System: Linear Scan	
Output Pulser [mV]:	**Measured Peaking Amplitude [ADC]:**
20	23.4
40	46.1
80	91.6
120	136.9
140	159.6
180	204.8
220	250.5
300	341.5
340	386.7
420	478.0
500	569.2
580	660.0
660	751.4
740	842.6
820	934.1
900	1025.0
980	1117.0
1060	1212.0
1140	1304.0
1220	1395.0
1300	1487.0
1380	1578.0
1460	1670.0
1540	1761.0
1620	1853.0
1700	1944.0
1780	2036.0
1820	2082.0
1860	2127.0
1900	2173.0

Table 1: Linear scan performed with the WASA readout system. The total error in the measured peaking amplitude is conservatively considered as being unity. For a correct comparison between the two sets of data the correction factor of 0.58 should be applied to the output pulser values.

data in two different measurement regions, resulting in an ADC resolution of approximately 0.5 mV per ADC.

Out of the fit results, the deviation to linearity is calculated in percent, and is presented in the right panels of the picture. The deviation is typically well below 1%, although unknown systematical effects (not investigated yet) appear.

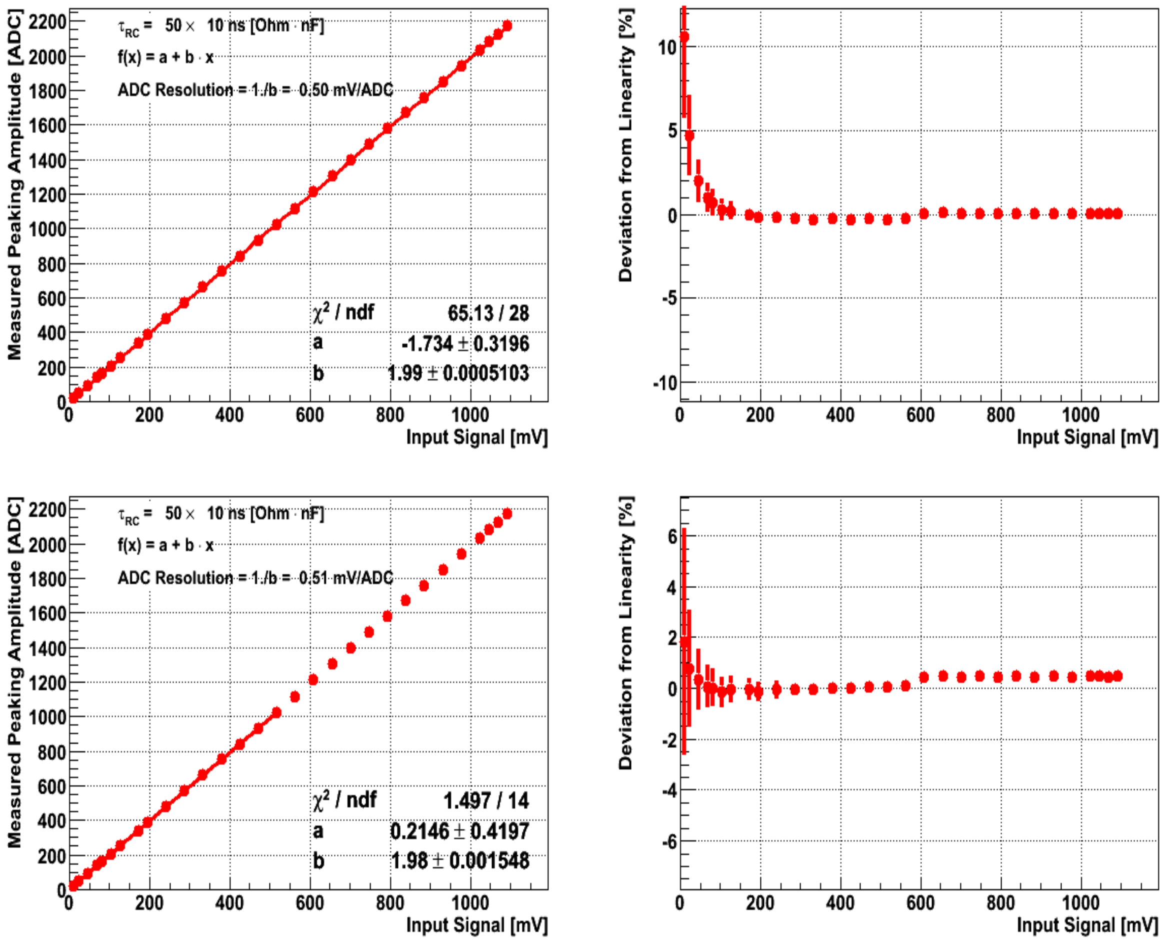

Figure 4: The ADC resolution is here extracted via a linear fit to the data of the scan with respect to the amplitude of the input voltage pulse.

Using the extracted ADC resolution, the total injected charge can be calculated for each waveform and the corresponding mean value can be measured for each input voltage amplitude. The results will be compared in the next section with the data obtained in the same experimental conditions with the ACQIRIS readout system.

3.4 Waveform Analysis: WASA vs ACQIRIS Comparison

The ACQIRIS readout electronics can store the waveform sampling values already in millivolt units, and performs a calibration at startup. We can thus measure the injected charge directly from the data, without any need of extra calibration.

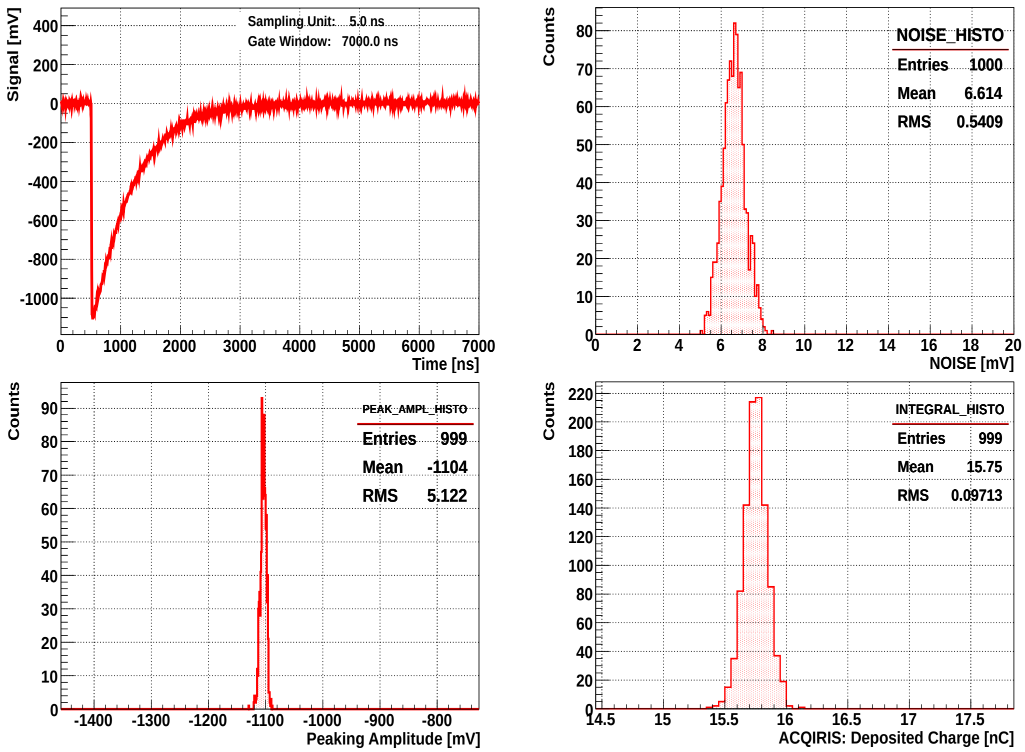

Figure 5: Typical histograms obtained during the waveform analysis with the ACQIRIS electronics. These examples were obtained with 1900 mV voltage amplitude provided by the pulse generator.

This type of measurement was performed for three amplitude values for the output voltage, 1900, 1220 and 580 mV, thus allowing for an estimation of the systematical evaluation of the total injected charge as measured by both readout systems. Please note that to the systematical effects should be also included possible effects due to the offline analysis.

As an example, the results for the output voltage pulse with amplitude of 1900 mV are presented in Fig. 5.

As above mentioned, the ACQIRIS system provides the data already in millivolts units, thus allowing a fast calculation of the deposited charge. The formula used is

$$INTEGRAL = \sum_i [Signal_i \cdot CONVERSION \cdot TIME\_SAMPLING\_UNIT] \ , \quad (2)$$

being the sum performed when the signal is found below a certain threshold (in this case the threshold is given by $3 \cdot \sigma_{noise}$), the TIME_SAMPLING_UNIT was 5 ns during this data taking, and the CONVERSION factor is simply 1/1000/50 (with 50 Ω impedance) to convert from millivolt to Coulomb.

The comparison of the integrated charge as measured by the two systems is presented in Fig. 6 for the values 1900, 1220 and 580 mV of the voltage pulse amplitude.

For all three experimental setups a relative 5% difference appears. Prelimi-

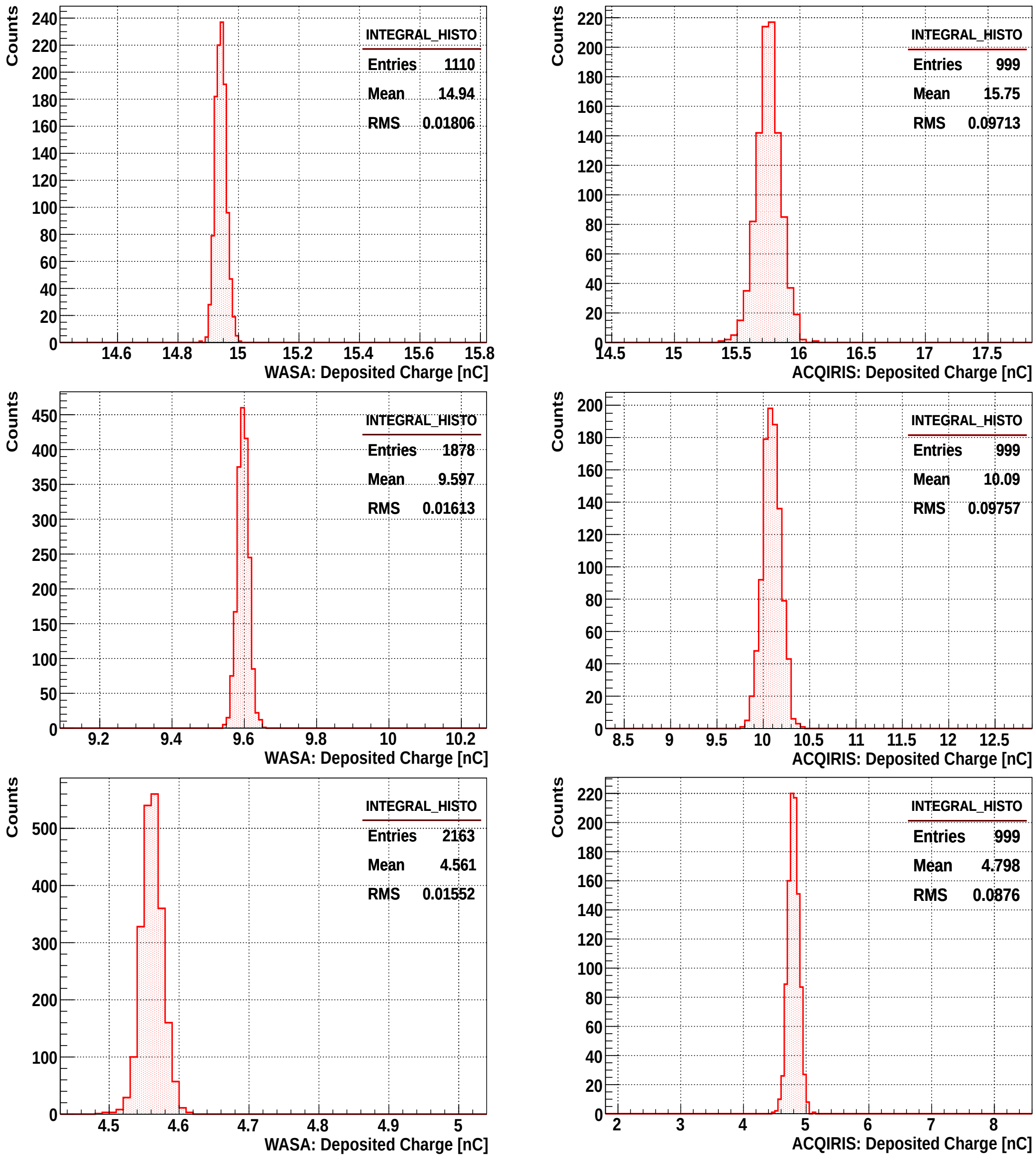

Figure 6: Integrated charge injected in the two readout systems for three values of the voltage pulse amplitude.

nary, for the moment this value is considered as a contribution to the systematical uncertainty of the measurement. It should be also mentioned that the ADC to mV conversion factor was derived by a direct observation in the oscilloscope with a large uncertainty. In the next measurements this conversion factor for the WASA system will be extracted by measuring the peaking amplitude with the ACQIRIS readout electronics in the same experimental conditions. Unfortunately, this way the results between the two devices will be not any more completely independent, although a large systematical scale uncertainty will be removed.

4 Precision of the ACQIRIS System with Respect to the Sampling Unit

Up to now the ACQIRIS system was used at the sampling unit of 5 ns which is the available setting closest to the 6.5 ns unit used in the WASA system. Although the comparison between the two systems has given promising consistent results, one should investigate how much could improve the measurement of the total injected charge when running the ACQIRIS system with finer sampling units.

The results for 5.0, 2.0, 1.0 and 0.5 ns is presented in Fig. 7 using a voltage pulse with amplitude 580 mV. The results show that for this type of analysis the variation in the calculation of the integral of the injected charge is at permill level, thus negligible. Having shown this feature, in the following analyses presented in this note the ACQIRIS system will be run with the sampling unit of 5 ns, as close as possible to the finest WASA setup (6.25 ns).

5 Analysis with an LED coupled to Vacuum PMTs

So far, waveforms generated by a pulse generator were investigated giving good agreement between the two readout system. The next natural step of the investigation was the waveform analysis using signals generated directly by photomultipliers. In this study the vacuum photomultiplier 8850 by BURLE Electron Tubes was used.

5.1 Test-Bench Description

The test-bench was modified to cope with signals from PMTs, and the experimental setup built to measure the properties of wave shifting fibers was used. The setup is shown in Fig. 8.

A 10 ns wide voltage pulse with 5 ns rise- and fall-time is sent to a blue LED which highlights the photocathode of the photomultiplier. Different intensities of the LED were used leaving the voltage pulse width unchanged, to avoid an increase of the rise-time of the current signal generated by the PMT, whose high-

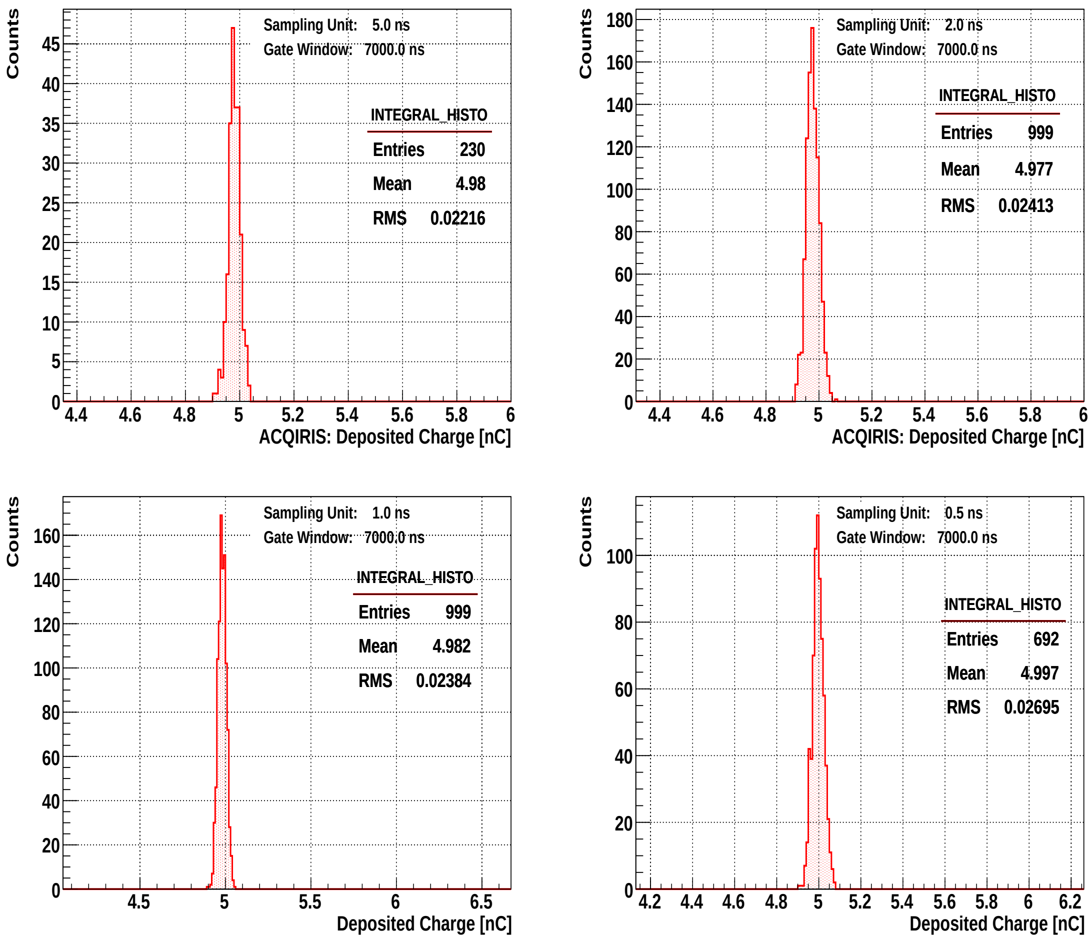

Figure 7: The integral of the injected charge is investigated with the ACQIRIS system at different sampling unit values.

voltage was left to its nominal value 1000 V. Instead, to change the intensity of the LED light output the voltage amplitude of the pulse generator was changed.

The pre-amplifier built for the Anger camera project [5] was used here, soon after the PMT, after modifying the RC stage to the following configuration

$$\begin{aligned} R &= 1.5\ k\Omega\ , \\ C &= 33\ pF\ + 68\ pF. \end{aligned} \tag{3}$$

With the above mentioned configuration of the voltage pulse generator and of the pre-amplifier no undershooting of the signal was observed.

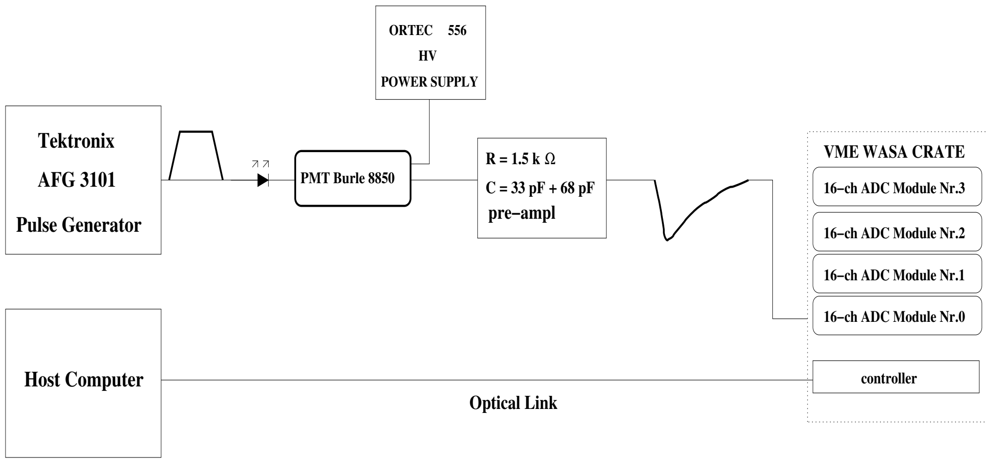

Figure 8: Test-bench setup used for the waveform analysis with the WASA readout system at FZJ using the signal generated by a photomultiplier. A similar experimental setup is used when using the ACQIRIS system; here network twisted cables are used for transmitting the data to the host computer.

5.2 Measurements with the WASA System

To verify the linearity of the system in the new experimental configuration for the WASA system a scan in the input voltage to the LED was performed. The response of the LED is typically not proportional to the input voltage, thus we used the results obtained with the ACQIRIS system to verify the linearity of the system (see Sec. 5.4).

The peaking amplitude distributions and a typical waveform (after pedestal subtraction) are presented for different values of the voltage input to the LED in the Fig. 9 - 13, and the results are shown in Tab. 2. Due to the limitations

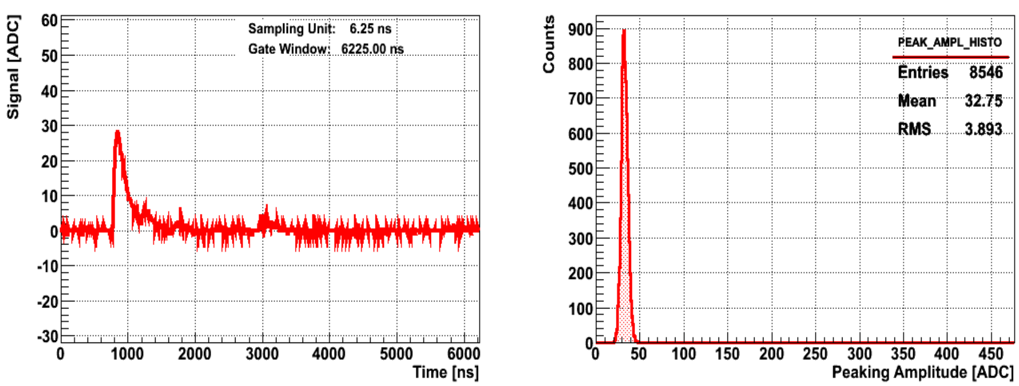

Figure 9: Waveform and peaking amplitude distribution measured with WASA electronics for 5.4 V voltage amplitude sent to the LED.

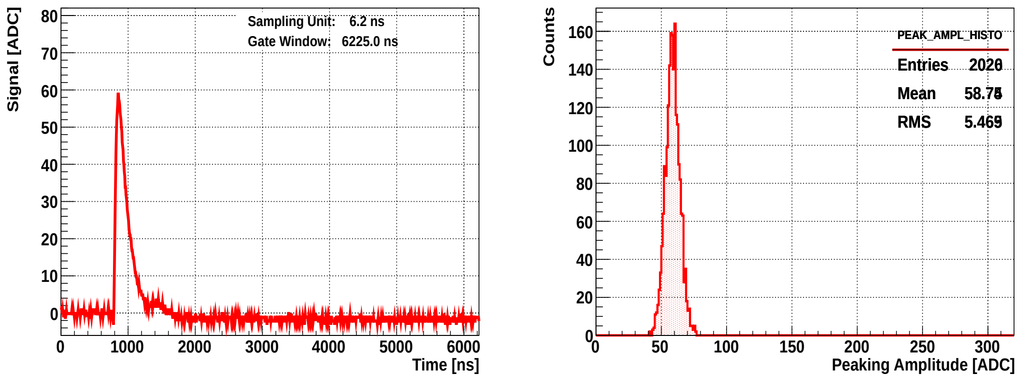

Figure 10: Waveform and peaking amplitude distribution measured with WASA electronics for 6.3 V voltage amplitude sent to the LED.

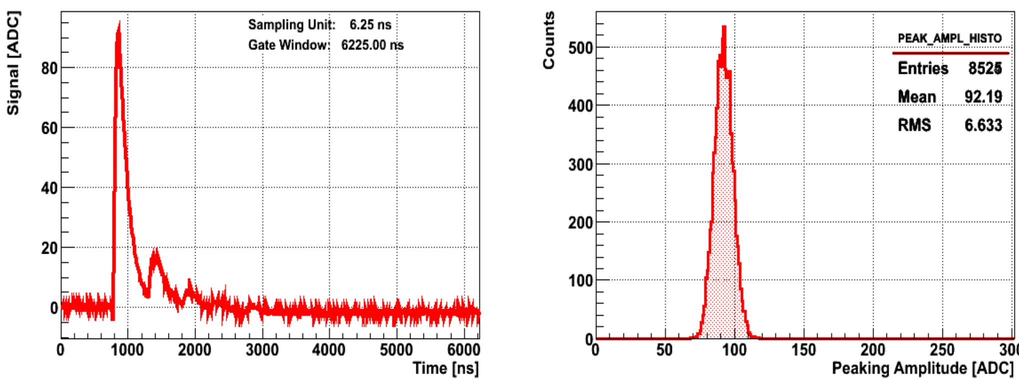

Figure 11: Waveform and peaking amplitude distribution measured with WASA electronics for 7.2 V voltage amplitude sent to the LED.

of the voltage pulse generator, values not larger than 10 V could be used, thus limiting the investigated ADC region of the WASA system.

WASA System: LED Intensity Scan	
Voltage Amplitude to LED [V]:	**Measured Peaking Amplitude [ADC]:**
5,4	33
6.3	59
7.2	92
8.1	132
9.0	175

Table 2: Scan performed with the WASA readout system increasing the LED intensity by changing the amplitude of the voltage pulse sent to the LED.

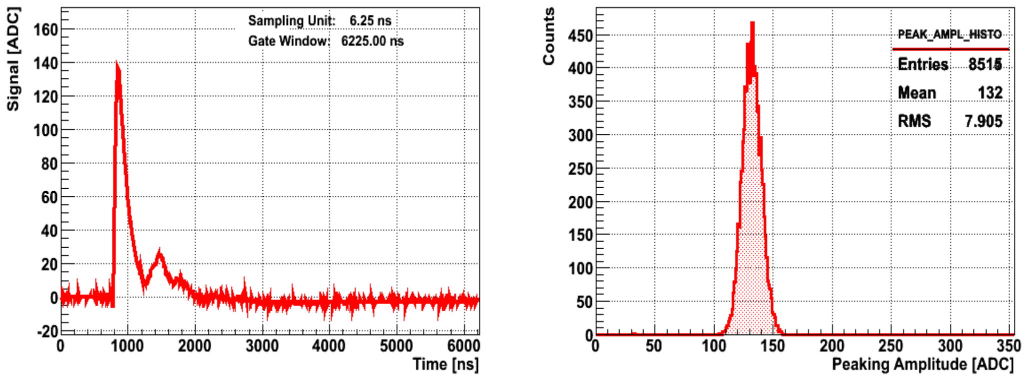

Figure 12: Waveform and peaking amplitude distribution measured with WASA electronics for 8.1 V voltage amplitude sent to the LED.

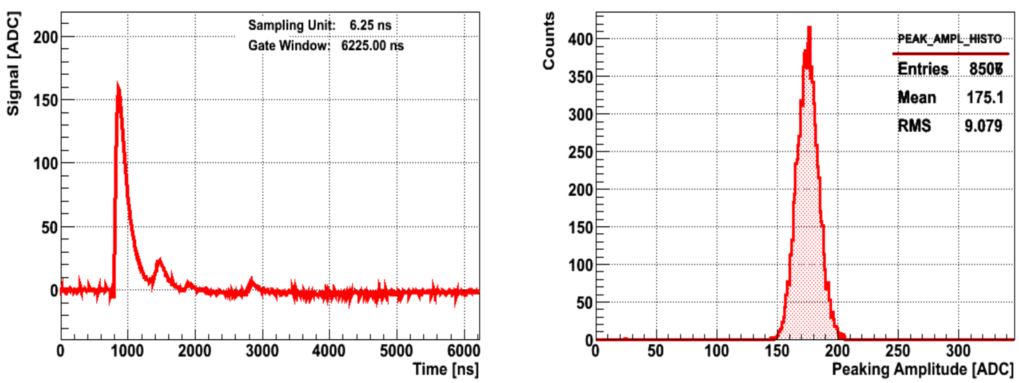

Figure 13: Waveform and peaking amplitude distribution measured with WASA electronics for 9.0 V voltage amplitude sent to the LED.

The conversion to millivolt of the values obtained in ADC units is provided by the similar measurements performed with the ACQIRIS readout system, shown in the next section. For the same amplitude of the voltage pulse to the LED a relation between the peaking amplitude value measured by WASA (in ADC units) and by ACQIRIS (in millivolt) was obtained.

5.3 Measurements with the ACQIRIS System

Within the similar experimental conditions, the same measurements were performed using the ACQIRIS readout electronics. The peaking amplitude distributions and the typical waveforms (after pedestal subtraction) are presented in the Fig. 14 - 18 for different values of the voltage input to the LED, and the results are shown in Tab. 3.

It is interesting to observe, as above mentioned, the non-linear LED intensity with respect to the amplitude of the input voltage pulse, Fig. 19. This is the

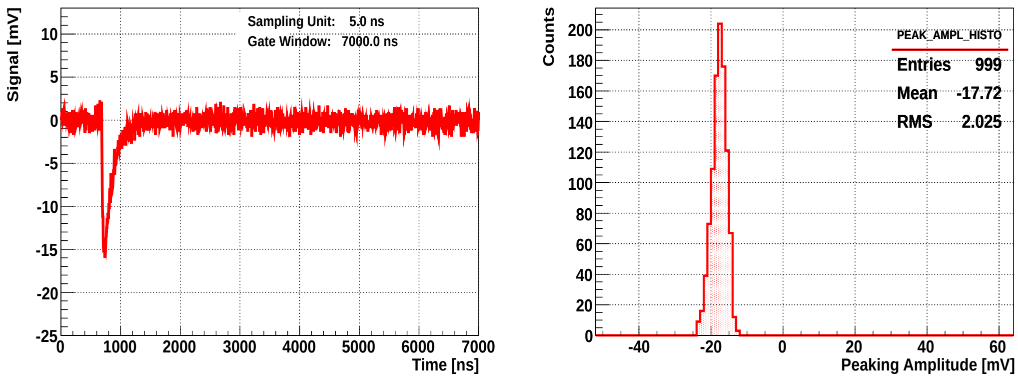

Figure 14: Waveform and peaking amplitude distribution measured with ACQIRIS electronics for 5.4 V voltage amplitude sent to the LED.

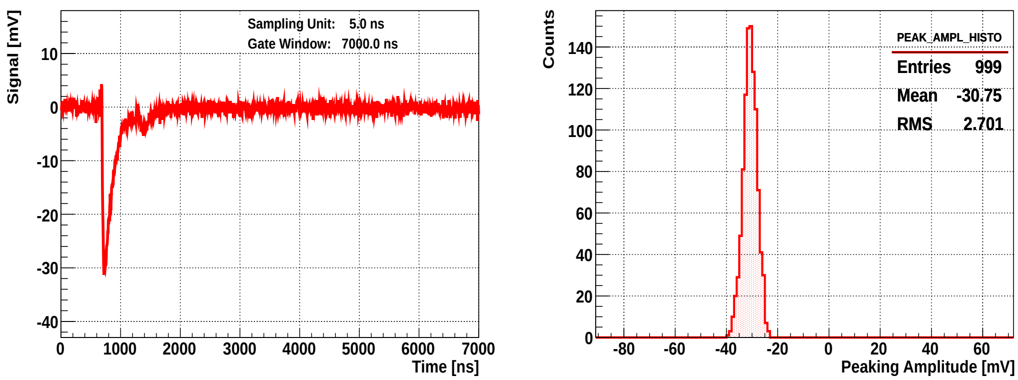

Figure 15: Waveform and peaking amplitude distribution measured with ACQIRIS electronics for 6.3 V voltage amplitude sent to the LED.

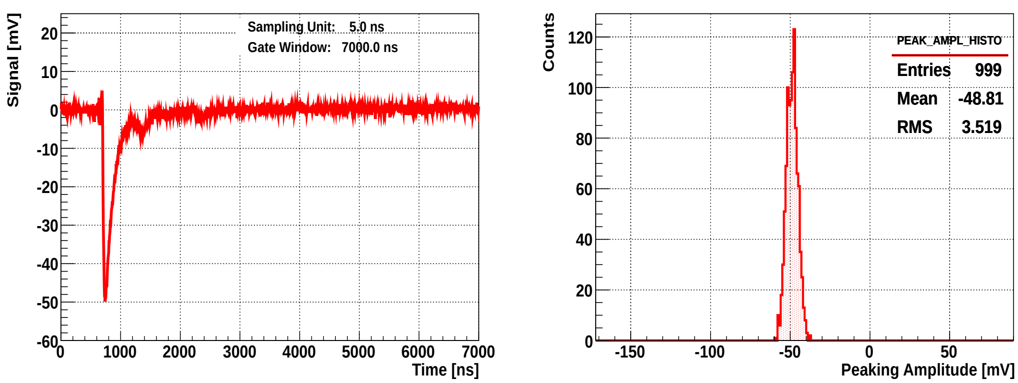

Figure 16: Waveform and peaking amplitude distribution measured with ACQIRIS electronics for 7.2 V voltage amplitude sent to the LED.

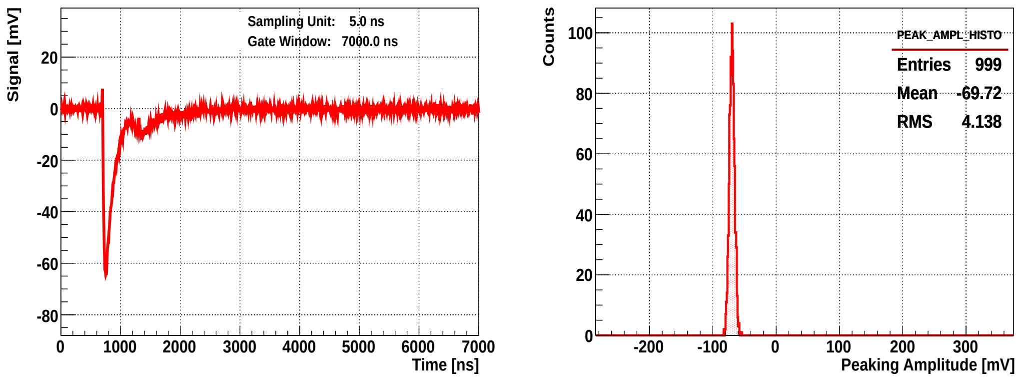

Figure 17: Waveform and peaking amplitude distribution measured with ACQIRIS electronics for 8.1 V voltage amplitude sent to the LED.

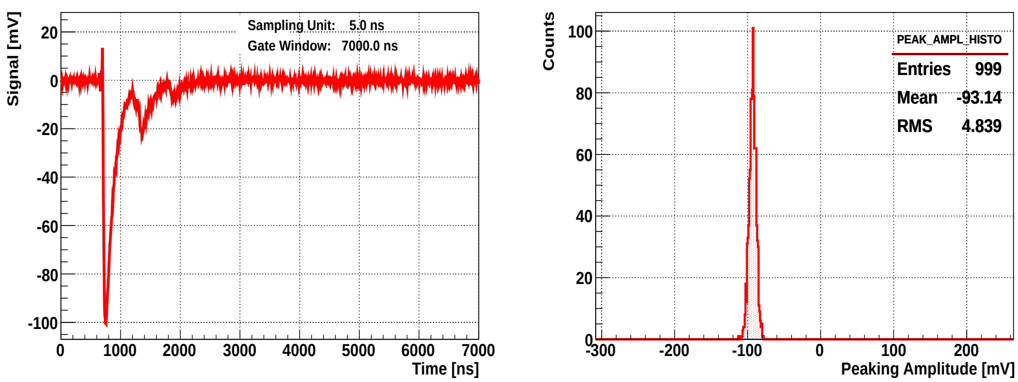

Figure 18: Waveform and peaking amplitude distribution measured with ACQIRIS electronics for 9.0 V voltage amplitude sent to the LED.

reason why one cannot use directly the setting of the voltage amplitude to calibrate the output of the photomultiplier.

ACQIRIS System: LED Intensity Scan	
Voltage Amplitude to LED [V]:	**Measured Peaking Amplitude [mV]:**
5,4	-18
6.3	-31
7.2	-49
8.1	-70
9.0	-93

Table 3: Scan performed with the ACQIRIS readout system increasing the LED intensity by changing the amplitude of the voltage pulse sent to the LED.

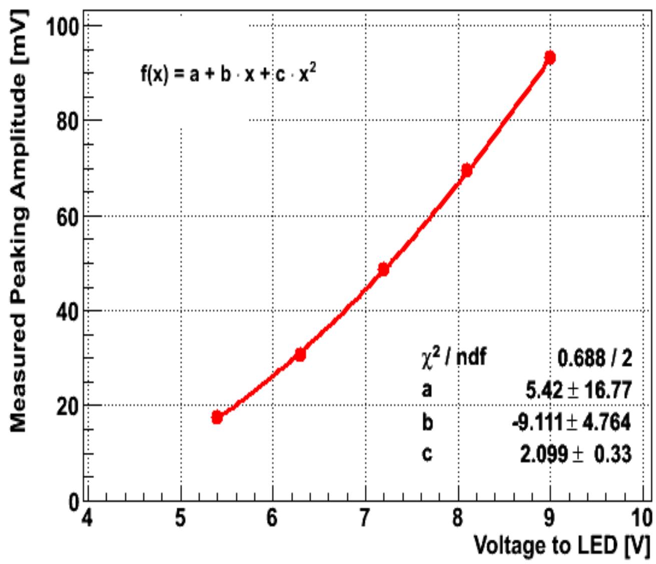

Figure 19: In the ACQIRIS system the peaking amplitude of the incoming waveforms was measured for different values of the amplitude for the voltage pulse sent to the LED. It is evident the non-linearity of the LED light output.

5.4 Linearity of the Experimental Setup System

By comparing the results of the peaking amplitude obtained with both readout systems in the same experimental setup configuration the linearity of the WASA system can be investigated in the system modified with the frequency filtering stage activated. The results are presented in Fig. 20, showing a very good linearity of the WASA ADC in the investigated region. Note that the WASA data have the pedestal (in this configuration at approximately 1880 ADC units) subtracted.

Out of the linear fit the ADC resolution can be also again calculated, resulting in 0.53 mV per ADC. This value is slightly different from what extracted in the previous measurement with the voltage pulse generator and the high-pass filter, possibly indicating a systematical uncertainty of few percent present in either the analysis chain, or in the hardware configuration, or in both.

5.5 Waveform Analysis: WASA vs ACQIRIS Comparison

By using the ADC resolution found in this experimental configuration the charge injected in the WASA system can be integrated, converted in Coulomb units and finally compared with the results obtained using the ACQIRIS electronics for the five chosen values of the voltage pulse amplitude.

The comparison of the integrated charge measured by the two systems is presented in Fig. 21 - 25 for the values 5.4, 6.3, 7.2, 8.1 and 9.0 V, respectively,

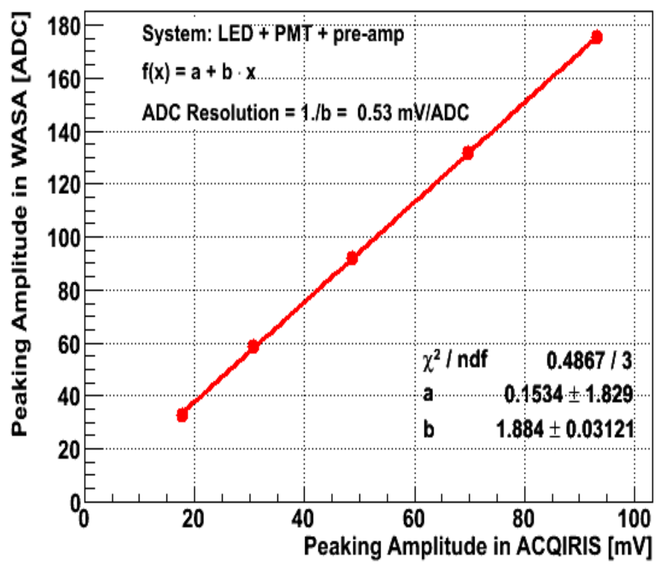

Figure 20: The linearity and the resolution of the WASA ADC were investigated by using the peaking amplitude values obtained by both readout systems.

of the amplitude of the voltage pulse sent to the LED.

For all experimental setups the integrated charge appears to be systematically slightly larger for the ACQIRIS system than what measured by the WASA system. The charge is quite small within the used setup of the measurements, possibly biasing (in the calculation stage) the evaluation of the relative difference at very small charge values (up to 8%); in principle this could be avoided running the PMT at higher gain. At large charge values instead the relative difference is approximately 4% stable. Note that the statistical uncertainty of the extracted means is at the per-mill level, in principle small enough not to

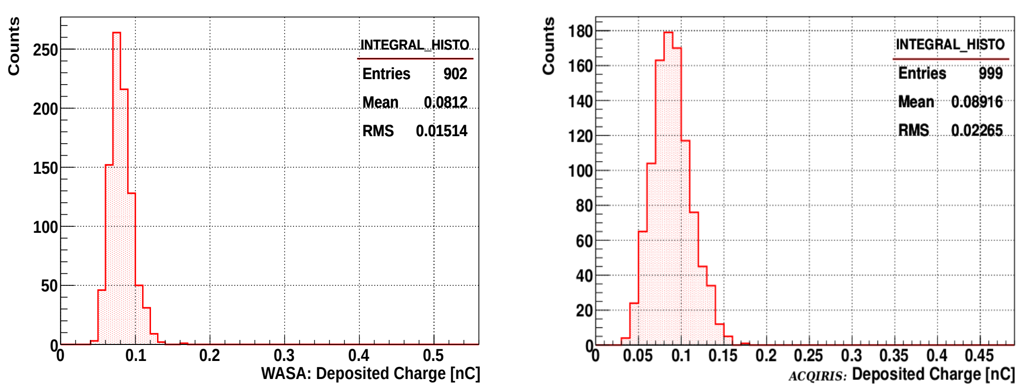

Figure 21: Integrated charge measured with both the WASA and the ACQIRIS for <u>5.4 V</u> voltage amplitude sent to the LED.

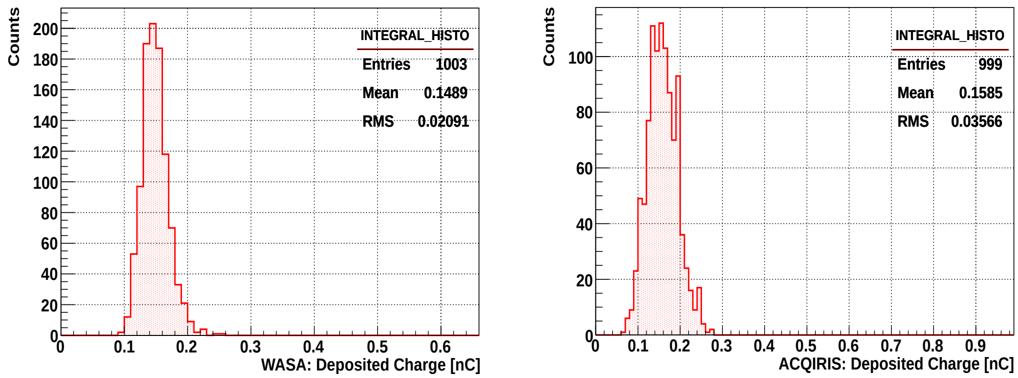

Figure 22: Integrated charge measured with both the WASA and the ACQIRIS for 6.3 V voltage amplitude sent to the LED.

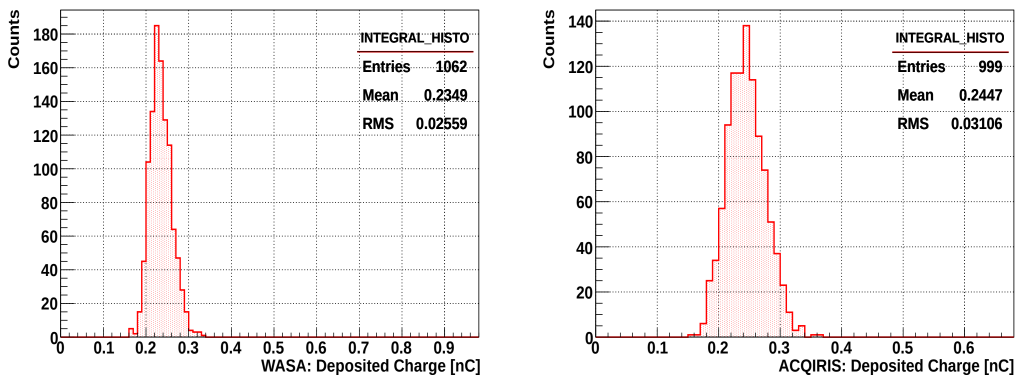

Figure 23: Integrated charge measured with both the WASA and the ACQIRIS for 7.2 V voltage amplitude sent to the LED.

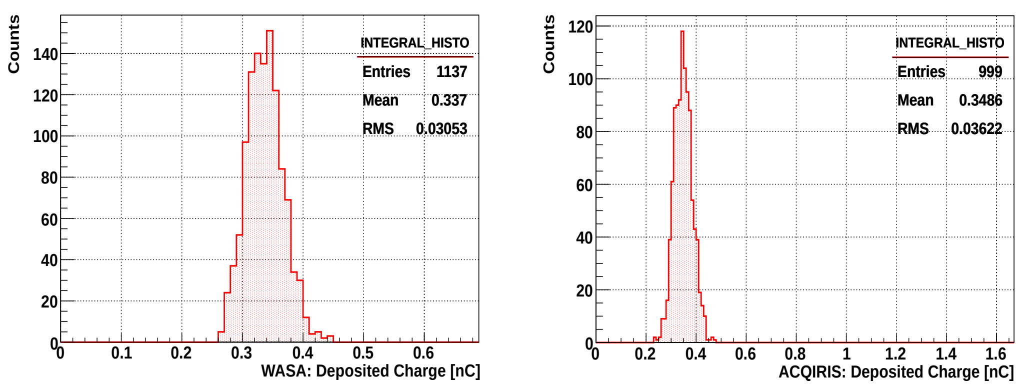

Figure 24: Integrated charge measured with both the WASA and the ACQIRIS for 8.1 V voltage amplitude sent to the LED.

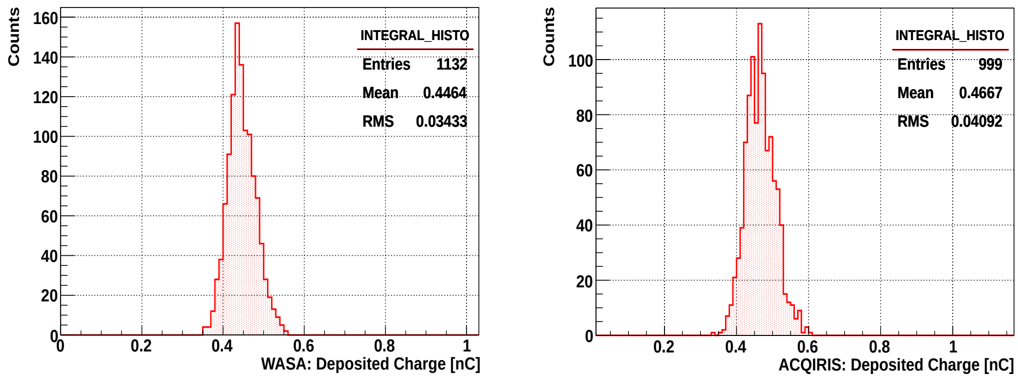

Figure 25: Integrated charge measured with both the WASA and the ACQIRIS for 9.0 V voltage amplitude sent to the LED.

bias the comparison of the measurements by the two systems.

6 Design of a new Transimpedence Amplifier: Analysis with the Voltage Pulse Generator

6.1 Transimpedence Amplifier Description

In order to make the data processing faster (e.g. with respect to the WASA differential ADC driver) a new transimpedence amplifier has been designed and build at ZEA-2 by J. Heggen. The test-bench configuration is similar to the setup presented in Fig. 2 with the introduction of the amplifier in between the SUCOBOX and the readout WASA/ACQIRIS module.

The schematic of the transimpedance amplifier is presented in Fig. 26. The

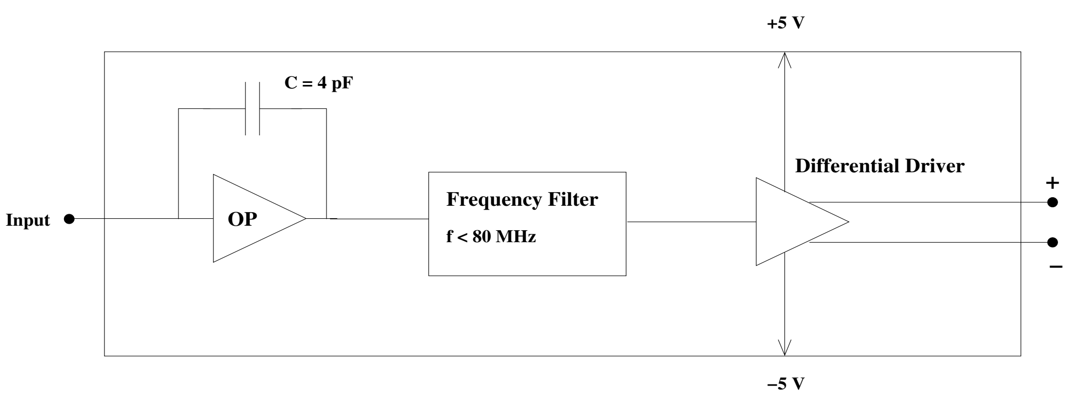

Figure 26: Schematic of the developed amplifier made of, in sequence, the transimpedence in parallel with a very low capacitance, a frequency filter and a differential driver.

WASA System: Linear Scan														
Output Pulser [mV]:														
3	5	8	11	14	17	20	23	26	29	32	35	38	41	42
Measured Peaking Amplitude [ADC]:														
154	255	405	555	707	858	1008	1160	1310	1459	1608	1757	1907	2057	2106

Table 4: Scan performed with the WASA readout system using the new transimpedence amplifier and **without frequency filtering**. The total error in the measured peaking amplitude is conservatively considered as being unity.

system is made of three stages, an operational amplifier (OP) in parallel with a very small capacitance such to minimize the charge integration and its characteristic time, thus fastening the signal processing. A frequency filters up to 80 MHz follows, and feeds a differential driver which performs the single-ended-to-differential conversion.

The bipolar output should be directly connected to the ADC converter. The use of a differential signal cable could help in reducing the signal distortion due to external noise sources, expecially when the device is located close to the current source, as the photomultiplier.

6.2 Measurements with WASA System: No Frequency Filter

To test the performance of the new amplifier the signal filtering has been first removed in both the amplifier and in the differential amplifier in the QDC WASA board (additionally here the capacitor at the signal input has been bridged). This procedure in the QDC module helped avoiding signal undershooting. In addition, the negative output of the amplifier was kept to the ground level. Typical results of the measurements are presented in the upper (bottom) panel of Fig. 27 for the input voltage amplitude of 3 (20) mV.

At the oscilloscope for the amplitude values of 1, 2 and 3 mV at the pulser generator the peaking amplitude values of 22.5, 45.0 and 67.5 mV are measured, resulting in a gain factor of 22.5 for the whole system (RC plus amplifier plus cable attenuation). As already mentioned, an unknown systematical uncertainty can potentially be present when extracting those values directly from the oscilloscope. As described in the previous sections, for each event the calculated pedestal is subtracted to the waveform sampling data bringing, as expected, the baseline to zero.

6.2.1 Linearity of the Experimental Setup System

A scan is performed, injecting in the WASA system waveforms with different values of the input voltage pulse amplitude, as shown in Tab. 4.

The above data are presented in Fig. 28. A linear function is fitted to the data in two different measurement regions, resulting in an ADC resolution of

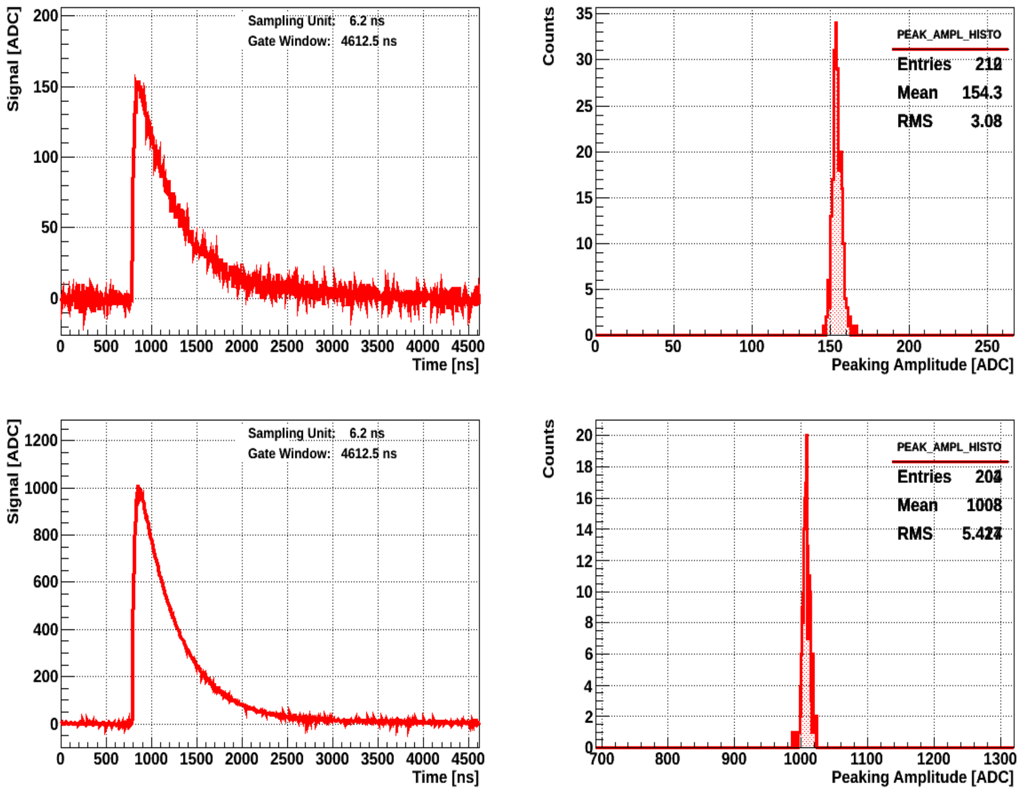

Figure 27: Waveform analysis with the WASA electronics using the developed transimpedence amplifier above described. Measurement done **without frequency filtering**. Examples obtained with 3 mV (upper panels) and 20 mV (bottom panels) of amplitude for the voltage pulse provided by the pulse generator.

approximately 0.46 mV per ADC. Note that the input signal is obtained using the values measured at the oscilloscope for 1, 2 and 3 mV (above described) and rescaling them for the larger amplitude values of the generated pulse.

From the fit results, the deviation to linearity is calculated in percent, and is presented in the left panels of the picture. The deviation is typically well below 1% in the investigated region. This extracted ADC resolution will not be used to calculate the total injected charge for each waveform due to the possible systematical uncertainty affecting the precise measurement of the peaking amplitude at the oscilloscope.

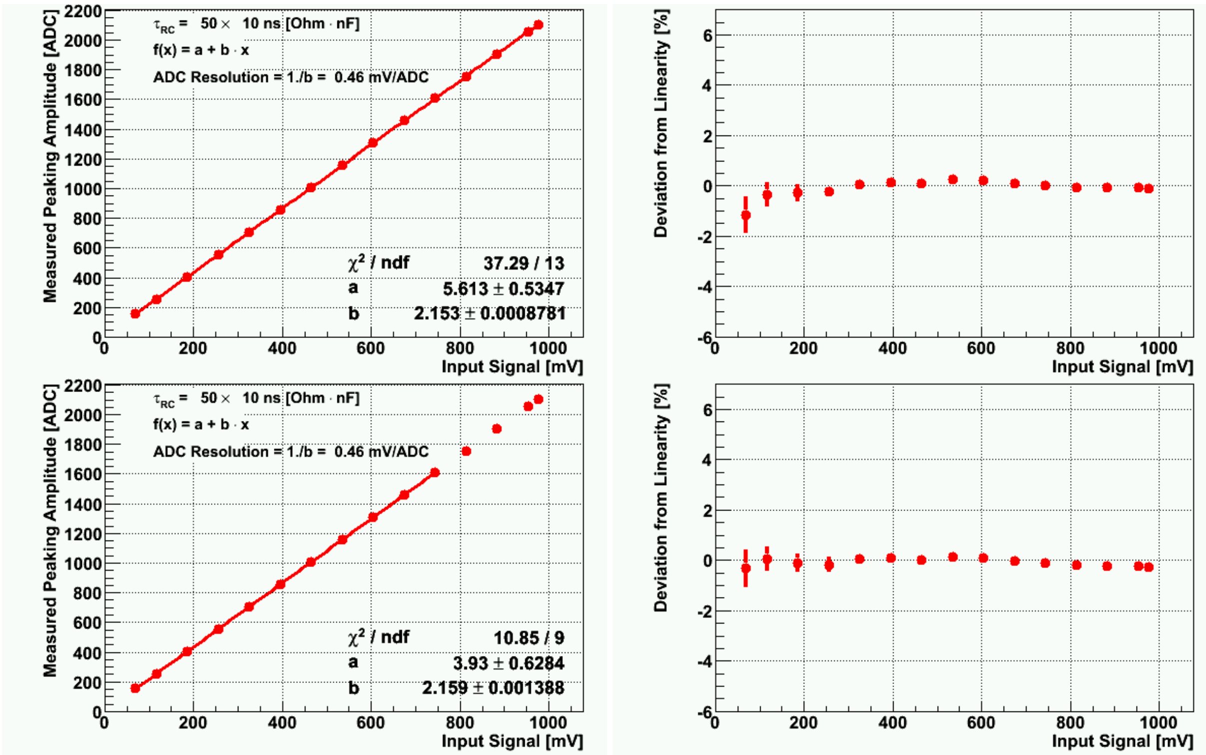

Figure 28: The ADC resolution is here extracted via a linear fit to the data of the scan in the amplitude of the input signal to the WASA board. The fit is performed in the whole scan region (upper panels) and in its lower part (lower panels), without affecting the extracted ADC resolution. Measurement done **without frequency filtering.**

6.2.2 Waveform Analysis: WASA vs ACQIRIS Comparison

With the same experimental setup some measurements have been performed using also ACQIRIS readout electronics. The values of 14, 26 and 38 mV for the amplitude of the input voltage pulse were used, and the corresponding relevant results are presented in Fig. 29.

Using the data obtained with the ACQIRIS system (in mV) the WASA data (in ADC) can be calibrated and converted in mV (0.46 mV per ADC unit). The comparison of the integrated charge as measured by the two systems is presented in Fig. 30 for the above three amplitude values of the voltage pulse.

For all three experimental setups a relative $1 - 2\%$ difference appears, better as in the previous setup. Preliminary, for the moment this value can be considered as the systematical uncertainty of the measurement.

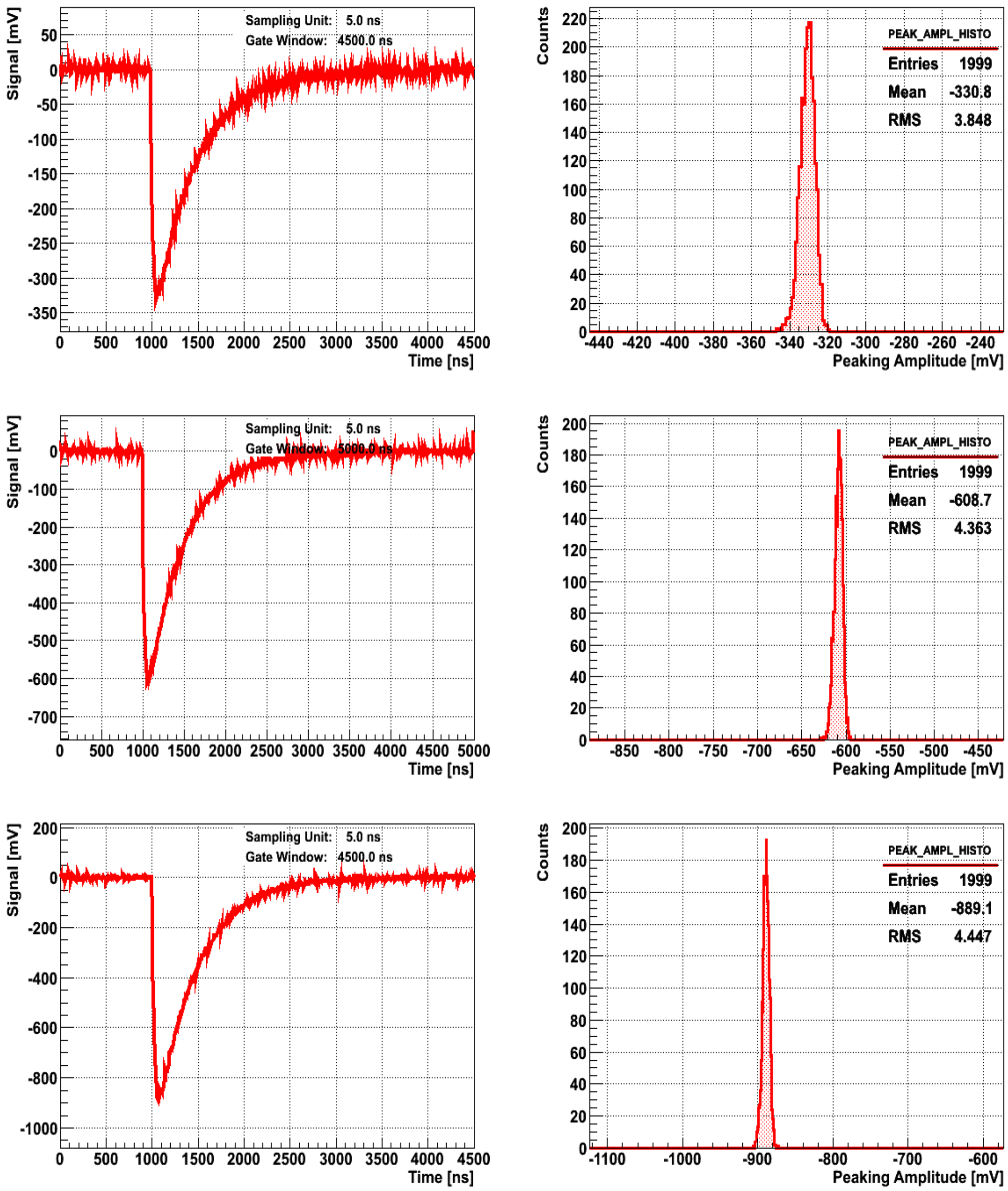

Figure 29: Waveform analysis performed with the ACQIRIS electronics using the new transimpedence amplifier and **without frequency filtering**. Results obtained with 14, 26 and 38 mV (upper, middle and bottom panels, respectively) voltage amplitude provided by the pulse generator.

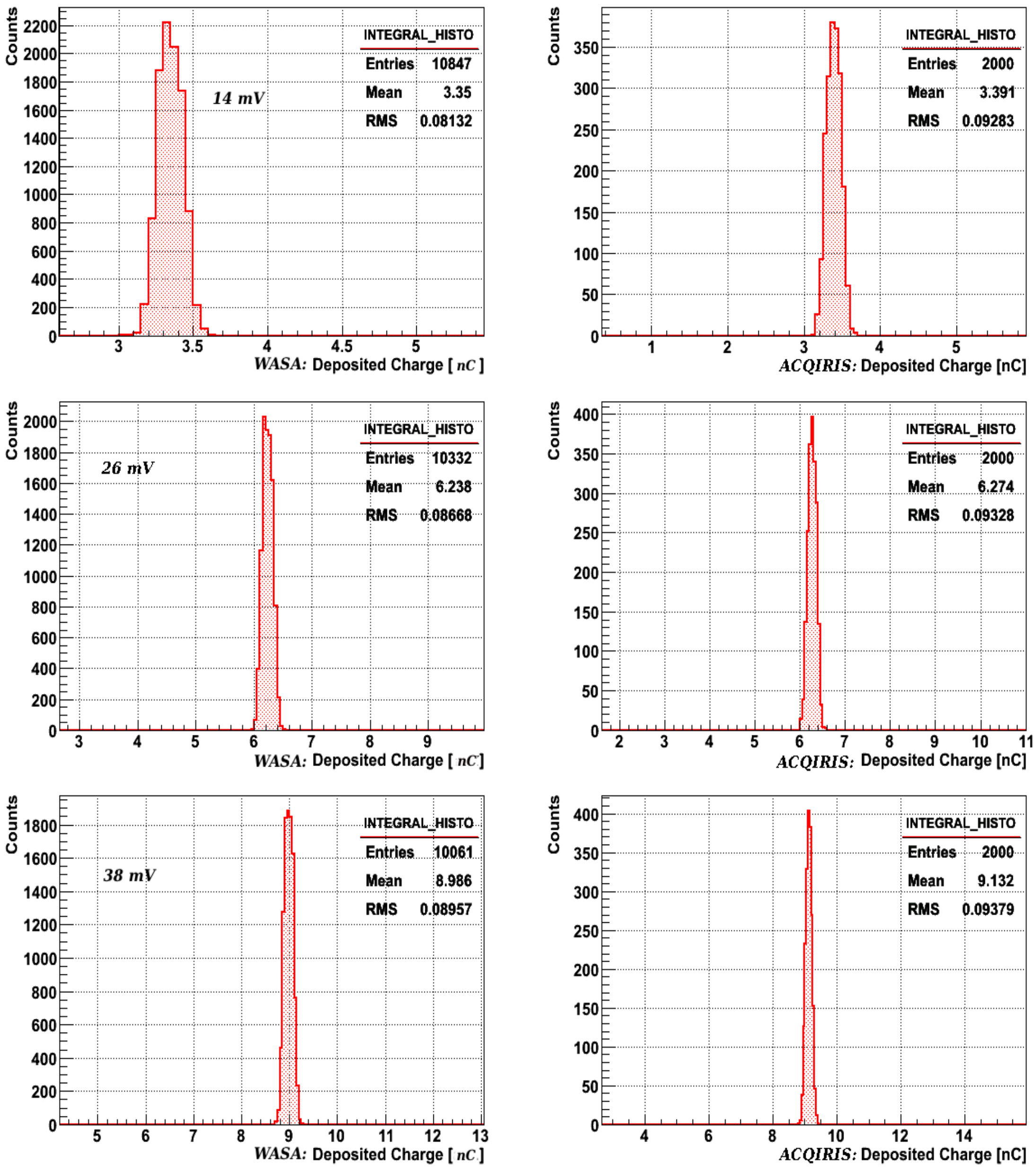

Figure 30: Integrated charge injected in the WASA and in the ACQIRIS readout systems with the new transimpedance amplifier **without frequency filtering** for the amplitude values of 14, 26 and 38 mV (upper, middle and bottom panels, respectively) for the voltage pulse.

6.3 Measurements with WASA System: With Frequency Filter

The next test was performed with the signal filtering stage ($f < 80$ MHz) active in the the new amplifier. Note that the modifications done in the QDC WASA board were kept to avoid signal undershooting. Again, the negative output from the amplifier was kept to the ground level. The results of the typical measurements is presented in the upper (bottom) panels of Fig. 31 for the input voltage amplitude of 10 (20) mV.

It is visible the higher gain of the amplifier with the frequency filter stage active, due to the presence of capacitors in that section of the device.

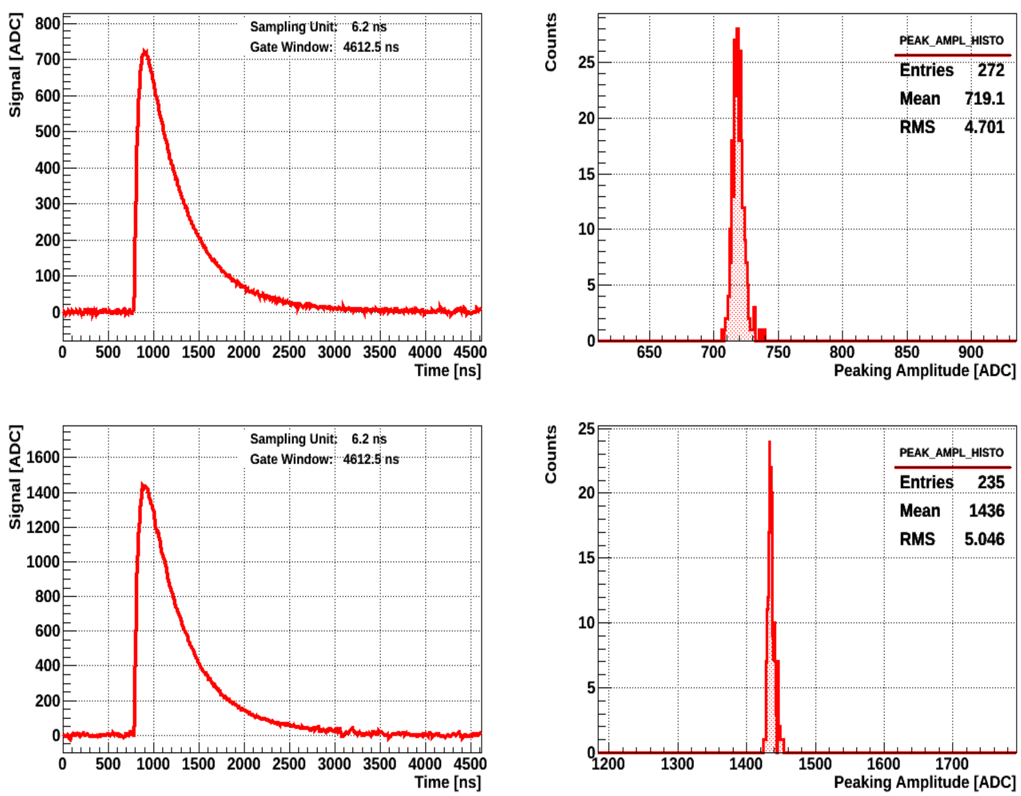

Figure 31: Waveform analysis with the WASA electronics using the developed transimpedence amplifier above described. Measurements done **with frequency filtering**. These examples were obtained with 10 mV (upper panels) and 20 mV (bottom panels) of voltage amplitude provided by the pulse generator.

6.3.1 Linearity of the Experimental Setup System

To investigate the linearity of the system with the frequency filtering stage active a scan is performed, injecting into the WASA system waveforms with different amplitude values for the input voltage pulse, as shown in Tab. 5.

With the same experimental setup some measurements were performed using also the ACQIRIS readout electronics. The values of 10, 20 and 26 mV for the amplitude of the input voltage pulse generator were used, and the corresponding relevant results are presented in Fig. 32.

The three ACQIRIS measurements of the peaking amplitude show the gain values 33.9, 33.5 and 33.6 for the used increasing values of the input voltage amplitude, with an absolute deviation of 0.4 and of a relative deviation up to 1% (which could be considered as the systematical uncertainty of this measurement).

Considering the mean gain value 33.7 allows to evaluate the peaking amplitude in mV of the input signal injected in the WASA readout electronics during the scan. The WASA scan data are then presented, after the above mentioned rescaling in Fig. 33.

A 2-parameter linear function is fitted to the data, resulting in an ADC resolution of approximately 0.47 mV per ADC unit. From the fit results, the deviation to linearity is calculated in percent, and found to be well below 1%. It is presented in the right panel of the picture.

6.3.2 Waveform Analysis: WASA vs ACQIRIS Comparison

The extracted ADC resolution will be used to calculate the total injected charge for each waveform in the WASA readout system.

The comparison of the integrated charge as measured by the two systems is presented in Fig. 34 - 36 for the three values of the voltage pulse amplitude used with the ACQIRIS electronics.

For all three experimental setups a relative $1 - 3\%$ difference appears, better as in the previous setup. Preliminary, for the moment this value can be considered as the systematical uncertainty of the measurement.

WASA System: Linear Scan								
Output Pulser [mV]:								
3	5	10	15	20	23	25	26	28
Measured Peaking Amplitude [ADC]:								
219	362	719	1079	1436	1650	1793	1865	2007

Table 5: Scan performed with the WASA readout system using the new transimpedence amplifier and **with frequency filtering**. The total error in the measured peaking amplitude is conservatively considered as being unity.

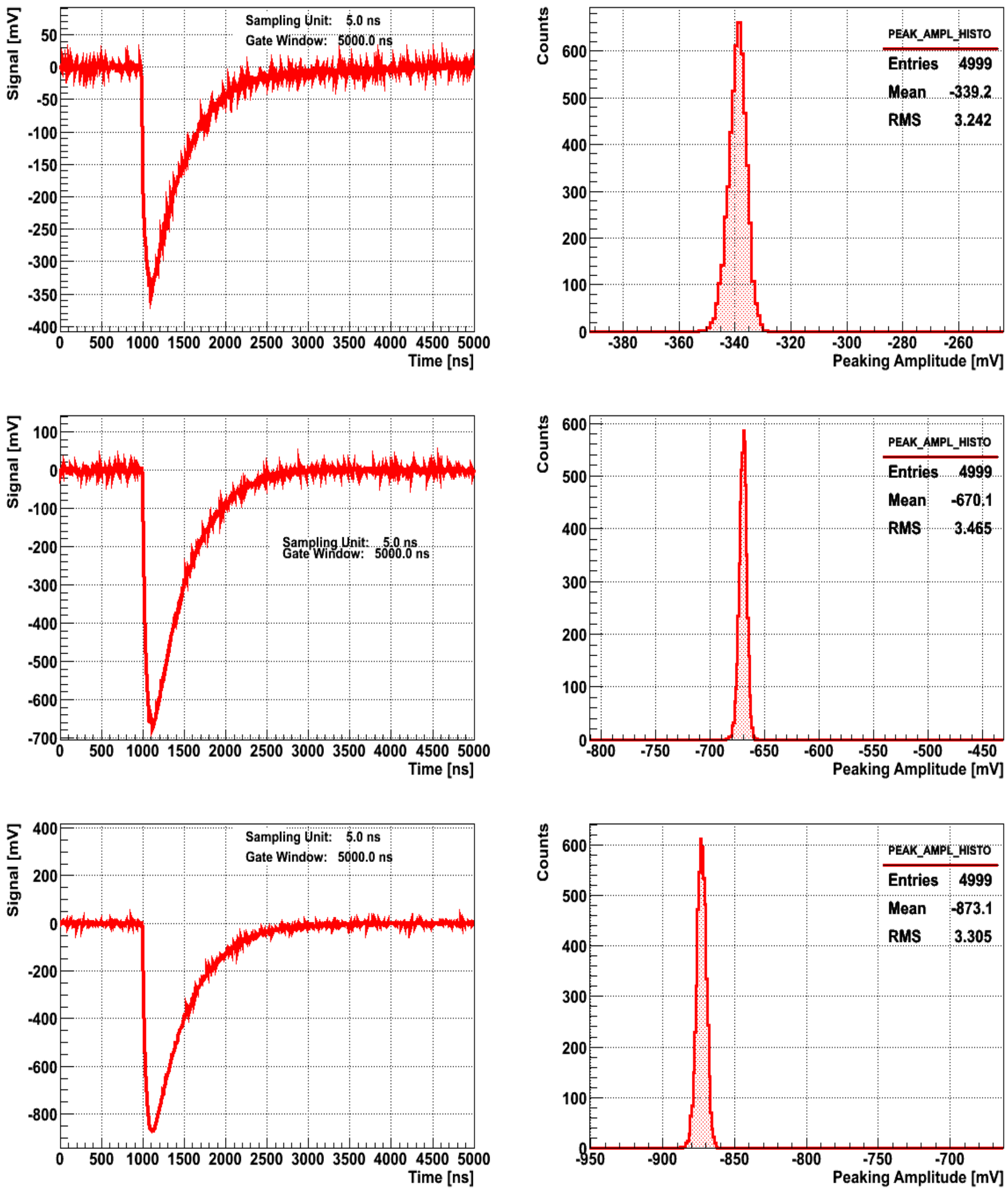

Figure 32: Waveform analysis with the ACQIRIS electronics with the new transimpedence amplifier and **with frequency filtering**. Measurements performed with 10, 20 and 26 mV (upper, middle and bottom panels, respectively) voltage amplitude provided by the pulse generator.

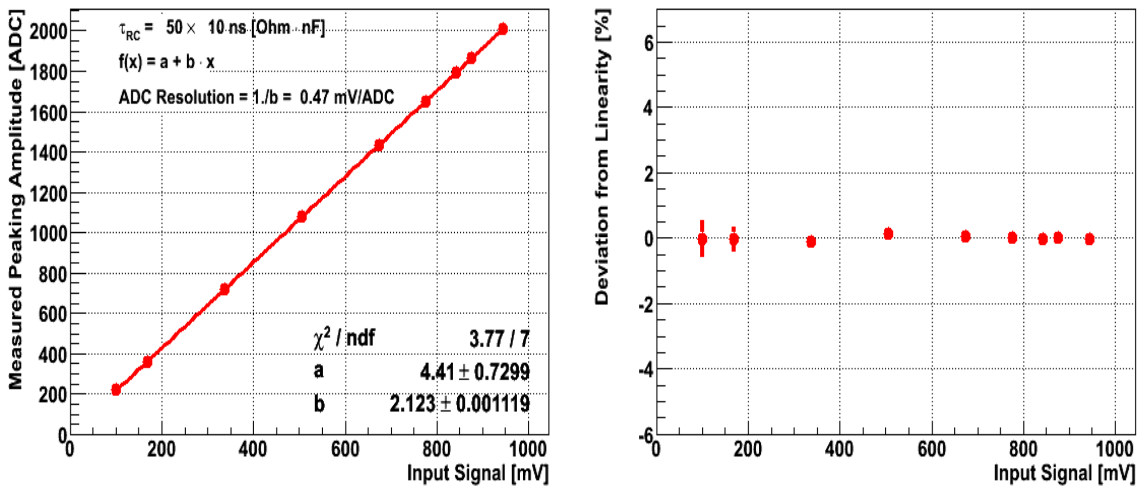

Figure 33: The ADC resolution is here extracted via a linear fit to the data of the linear scan in the amplitude of the input signal to the WASA board (left panel). The deviation to linearity shows a system linear within 1% within all available ADC range (right panel). The measurement was performed with the new transimpedence amplifier and **with frequency filtering**.

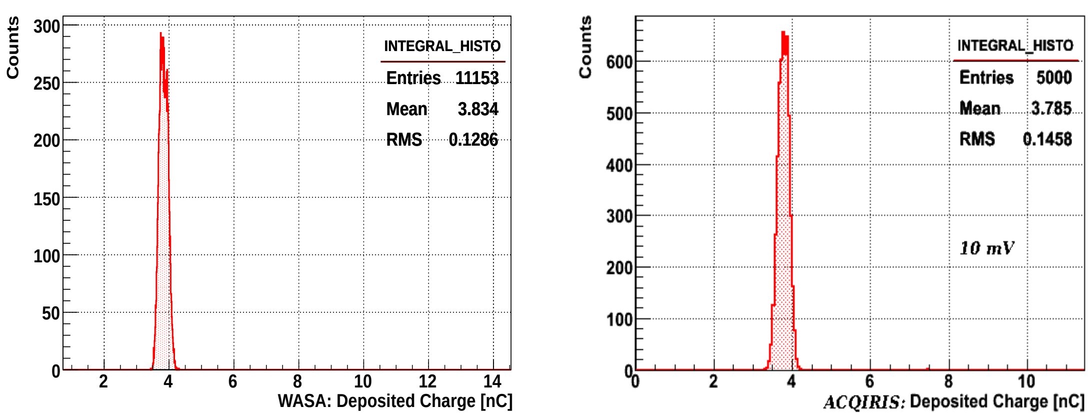

Figure 34: Integrated charge injected in the WASA and in the ACQIRIS readout systems with the new transimpedance amplifier **with frequency filtering** for the value 10 mV of the voltage pulse amplitude.

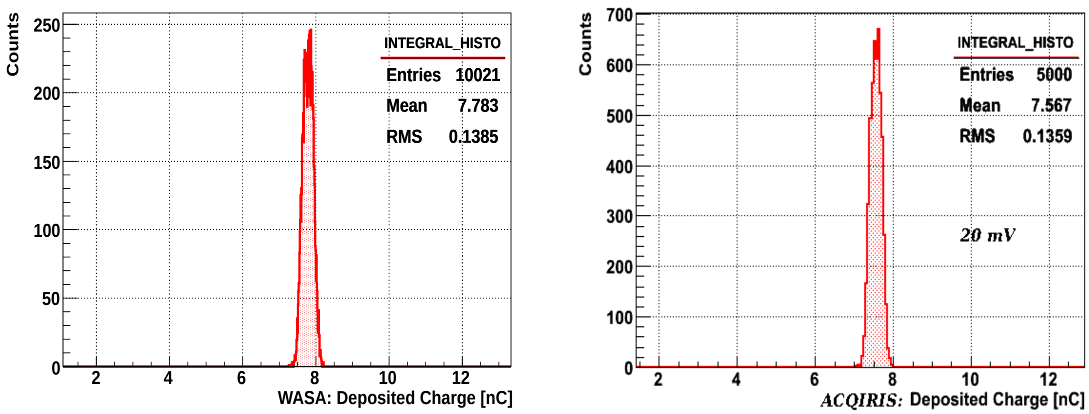

Figure 35: Integrated charge injected in the WASA and in the ACQIRIS readout systems with the new transimpedance amplifier **with frequency filtering** for the value 20 mV of the voltage pulse amplitude.

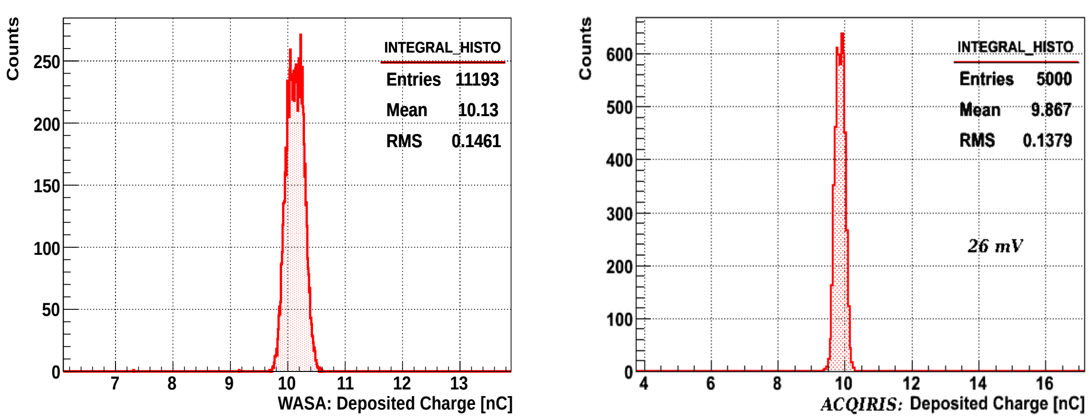

Figure 36: Integrated charge injected in the WASA and in the ACQIRIS readout systems with the new transimpedance amplifier **with frequency filtering** for the value 26 mV of the voltage pulse amplitude.

6.4 Measurements with WASA System: Differential Signal

The last test done with the new amplifier was performed using the complete differential signal at its output (as shown in Fig. 26), connecting both poles directly to the ADC in the QDC board. When located close to the current source this signal transmission technique should help to limit deformation of the signal along its way to the ADC module.

Examples of these measurements are presented in the upper and bottom panels of Fig. 37 for the input voltage amplitude of 5 and 15 mV, respectively. It is visible the higher gain of the amplifier with the differential signal output,

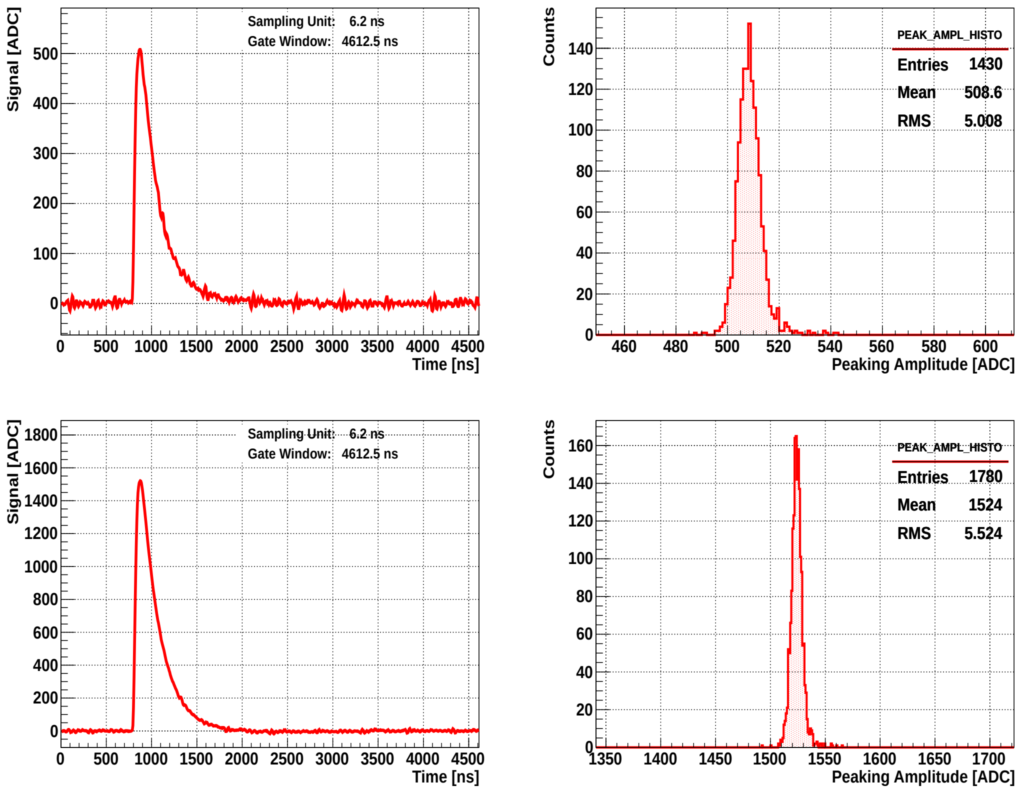

Figure 37: Waveform analysis with the WASA electronics using the developed transimpedence amplifier above described. Measurements done **with differential output**. These examples were obtained with 5 mV (upper panels) and 15 mV (bottom panels) of voltage amplitude provided by the pulse generator.

which is expected to be approximately double than when coupling the negative output pin to the ground, as in the previous section with a single-ended output cable of the amplifier.

6.4.1 Linearity of the Experimental Setup System

Using a differential signal no direct comparison could be done with the ACQIRIS readout system, which has single-ended input connectors. Nevertheless it is interesting to verify the linearity of the experimental system, after the applied modifications. To investigate the linearity of the system a scan is performed, injecting in the WASA system waveforms with different amplitude values of the input voltage pulse, as shown in the Tab. 6.

When comparing the current results with what obtained with the amplifier in single-ended output mode (and the frequency filtering active in both case) shown in Tab. 5, the signal appears to have the expected double amplitude.

WASA System: Linear Scan	
Output Pulser [mV]:	**Measured Peaking Amplitude [ADC]:**
3	306
5	509
7	711
9	914
11	1117
15	1524
17	1726
19	1930

Table 6: Scan performed with the WASA readout system using the new transimpedence amplifier and **with differential output**. The total error in the measured peaking amplitude is conservatively considered as being unity.

Without any information from the ACQIRIS system, we cannot have a precise measurement of the system gain (the input voltage from the pulse generator is in millivolt, while the measurement of the peaking amplitude performed by WASA after the amplification is in terms of ADC). Nevertheless the linearity can be investigated comparing the measurements by WASA with respect to the voltage amplitude provided by the input pulser (the use of the gain factor would result infact simply in a rescaling of the reference input).

The WASA scan data are then presented, without the above mentioned rescaling, in Fig. 38. A two-parameter linear function is fitted to the data, and the deviation to linearity, calculated in percent, is presented in the left panel of the picture. The deviation is well below 1%.

Using the mean mV/ADC conversion factor 0.46 found in the previous analyses the integrated injected charge can be calculated, and compared with the peaking amplitude (also converted in millivolts) of the waveform. The results are presented in Fig. 39 for all the values of the pulse amplitude used in the scan.

The system and the analysis algorithm provide results linear well within 1%. The slightly high value of the χ^2 is possibly given by the underestimation of the uncertainty of the measurements. Following the recommendations in the Particle Data Book [6], the uncertainty could be enlarged with a common factor bringing the χ^2 down to a reasonable value. The "extra" uncertainty should be considered as a contribution to the systematical uncertainty of the measurements.

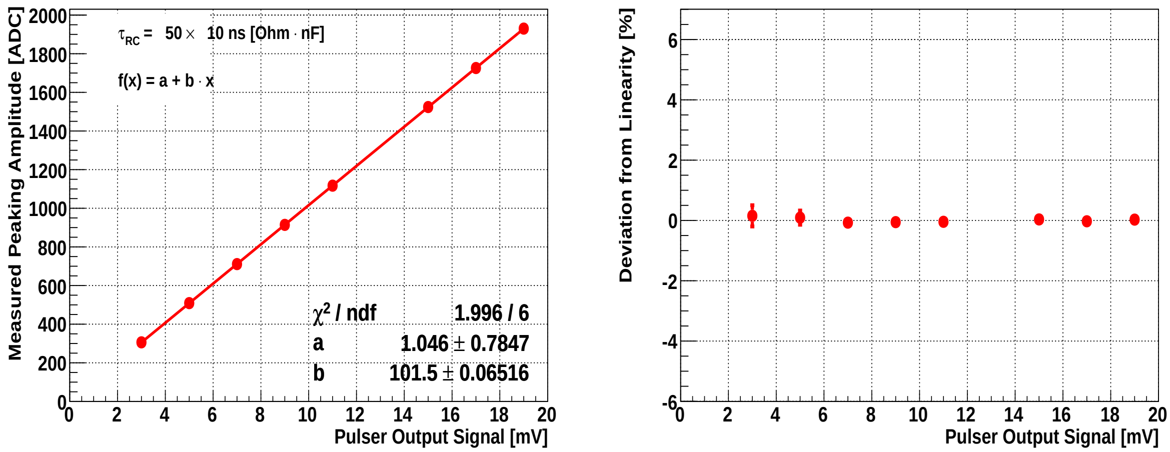

Figure 38: The linearity of the experimental system is here extracted via a linear fit to the data of the scan w.r.t. the amplitude of the input signal sent by the pulser to the WASA board. The deviation to linearity shows that the system is linear within 1% through all available ADC range (right panel). This measurement was performed with the new transimpedence amplifier and **with differential output**.

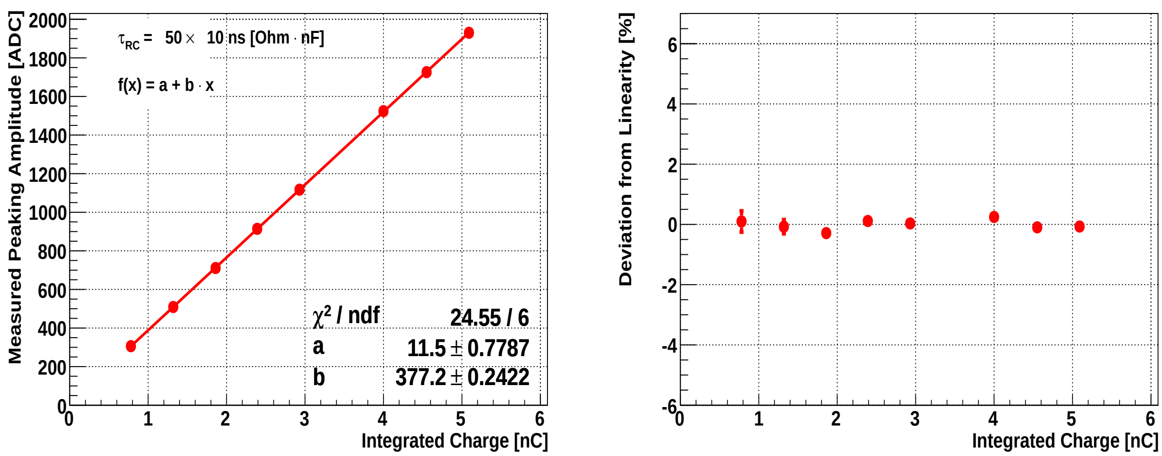

Figure 39: The peaking amplitude is presented with respect to the corresponding integrated charge showing a good linearity. The deviation to linearity shows that the used analysis algorithms provides results linear within 1% through all available ADC range (right panel). This measurement was performed with the new transimpedence amplifier and **with differential output**.

7 Conclusions

During summer 2013 a preliminary waveform analysis was performed using two readout electronics systems, ACQIRIS DC282 and WASA, to investigate their precision in measuring the collected charge by the devices using several types of amplifier configurations and different amount of injected charge. The goal of the analysis was to verify the possibility to use in future applications for neutron detection one of the two systems without experiencing unexpected biases in the measurement. It is clear that it would be desirable in the future to perform additional measurements, as on the rate efficiency, gain adjustment, pedestal uniformity and cross-talk.

For each experimental configuration the results show a relative agreement between the two devices within few percents in the charge measurement. Also, some discrepancy in the extracted ADC resolution of few percents was observed when using different experimental setups. Being the results preliminary, no further investigation was done on the source of this systematical uncertainty, although the measurements suggest a dependence on the correct ADC calibration in the WASA; this feature should, in principle, be a minor issue, due to the possibility to perform that calibration in a more controlled and stable experimental setup.

Quite interesting is the use of a new transimpedance amplifier with differential output in order to minimize, when locating the device close to the current source, the signal distorption when picking up noise from neighbouring instrumentation in an experimental hall like FRM-II. This device in the used experimental test-bench setup showed a linear response well below 1%.

As next evaluation, it is forseen to use the new transimpedence amplifier in single-ended mode in combination with the available 16 input channel ACQIRIS DAQ crate (which processes signals in single-ended mode) to run a new Anger Camera prototype (already built at ZEA-2), based on scintillating plates, and made of 4x4 vacuum photomultipliers R268 by Hamamatsu. The measurements will be made initially with the neutron Cf^{252} source availabe in our laboratory, and the results will be published as soon as they will be available.

The results presented in this work should ensure the possibility to use the WASA system in the waveform analysis, expecially in the case of need to build and run the Anger Camera with a larger spatial coverage and input channels, being the WASA crate (by WIENER [7]) capable to host up to 15 readout modules (plus the interface module to the external computer), resulting theoretically in 240 readout channels.

Acknowledgments

The authors acknowledge A. Erven, J. Heggen and C. Wesolek for their technical contribution to some results here presented. We are also grateful to the ZEA-2 Management for its efforts in supporting this project.

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