Digital Positron Lifetime: The Influence of Noise

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Introduction

While the use of computers and digital equipment more and more rules the daily live especially of scientists, the usage of computers for PALS is more or less limited to the evaluation of the final spectra. The advent of (ultra-)fast digitizers and fast enough computers opens up new possibilities of connecting the photomultipliers directly to the computer. Now all the evaluation of the anode-pulse can be done in software, thus replacing the almost 50 years old analog electronic chain.

As this change of the setup introduces new sources for errors, it is vital to know which part of the processing introduces which errors. Several Monte-Carlo-Simulations where done to simulate the different parts of the combination of photomultiplier, pre-amplifier and ADC.

Investigations on their influence on the final result have been made both independent of each other and in combination. The results show that the vertical resolution has a very big influence on the timing resolution partly because of the limited number of bits (usually 8-10bits) available in this range of needed sampling rates of 2-8GS/s and partly because of the noise introduced by pre-amp and ADC reducing the bit-depth to an effective bit-depth as low as 6 bits. Apart from the uncertainties from scintillator and photomultiplier this introduces a limit on the timing resolution which might come as a surprise.

Additionally noise reduction via low-passfiltering is applied to the raw-pulses to test wether this improves the timing resolution.

Simulated Pulses

The theory of signal processing says that the discrete event of the gamma-quantum is folded with the resolution-functions of scintillator, photomultiplier and used analog electronics. These are widely accepted to be following the Gaussian-function:

$$y \sim \exp\left(-\frac{(x-x_0)^2}{2\sigma^2}\right)$$

As the delta peak of a discrete event folded with the gaussian function results in the gaussian function itself, at least the rising slope of the photomultipliers signal can be estimated very well by this function. The works of [Nissila2005, Aavikko2005] also show that the gaussian function can be used for interpolation on the real data, but this is slow compared to other methods because of the addtional step of fitting the gaussian to the data.

The upper row of Figure 1 shows four pulses as generated for these simulations. The shape and risetime are similar to what we measured with LSO-scintillators on Hamamatsu H3378-50 photomultipliers.

Parameters for the Simulations

For the pulses several parameters can be set in the EPOS-Software [EPOS]:

1. The amplitude (and distribution) of each channel individually, used to simulate a 22-Na energy spectrum.
2. The distribution of the time-spread between the pulses.
3. The bit-depth of the vertical resolution.
4. The level of white noise added to simulate the analog electronics.

Figure 1: Raw and Lowpass-filtered Pulses

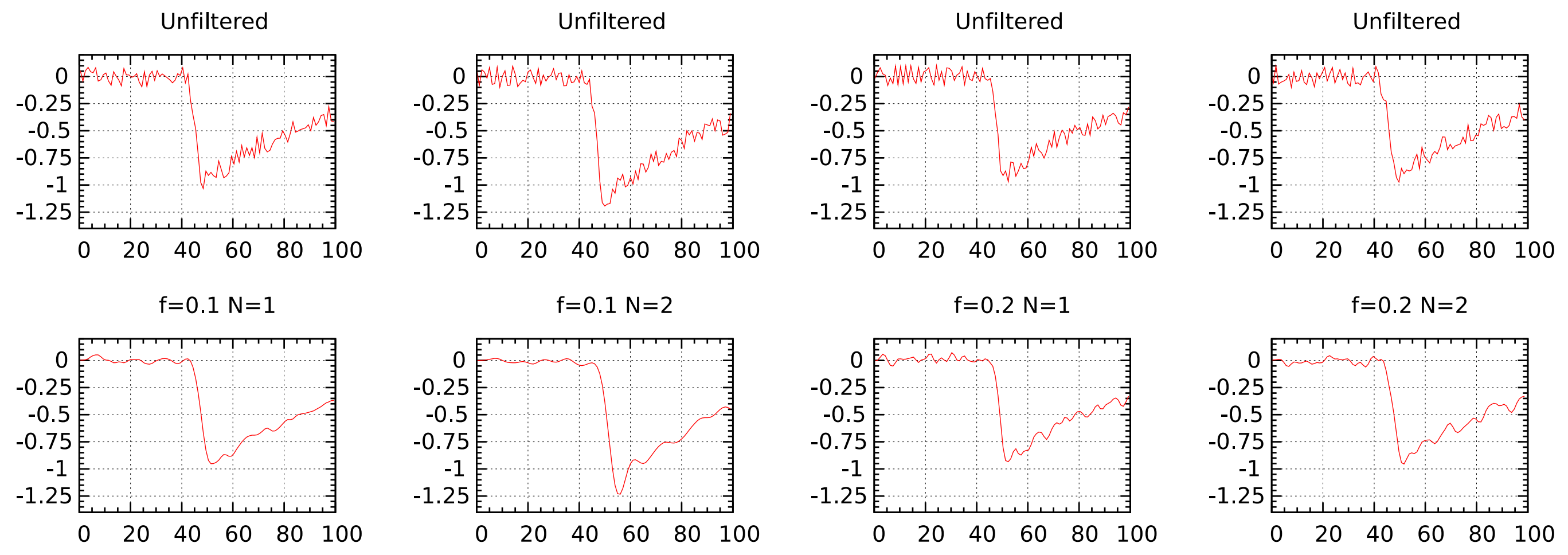

Figure 2: Response of the Butterworth-Lowpass

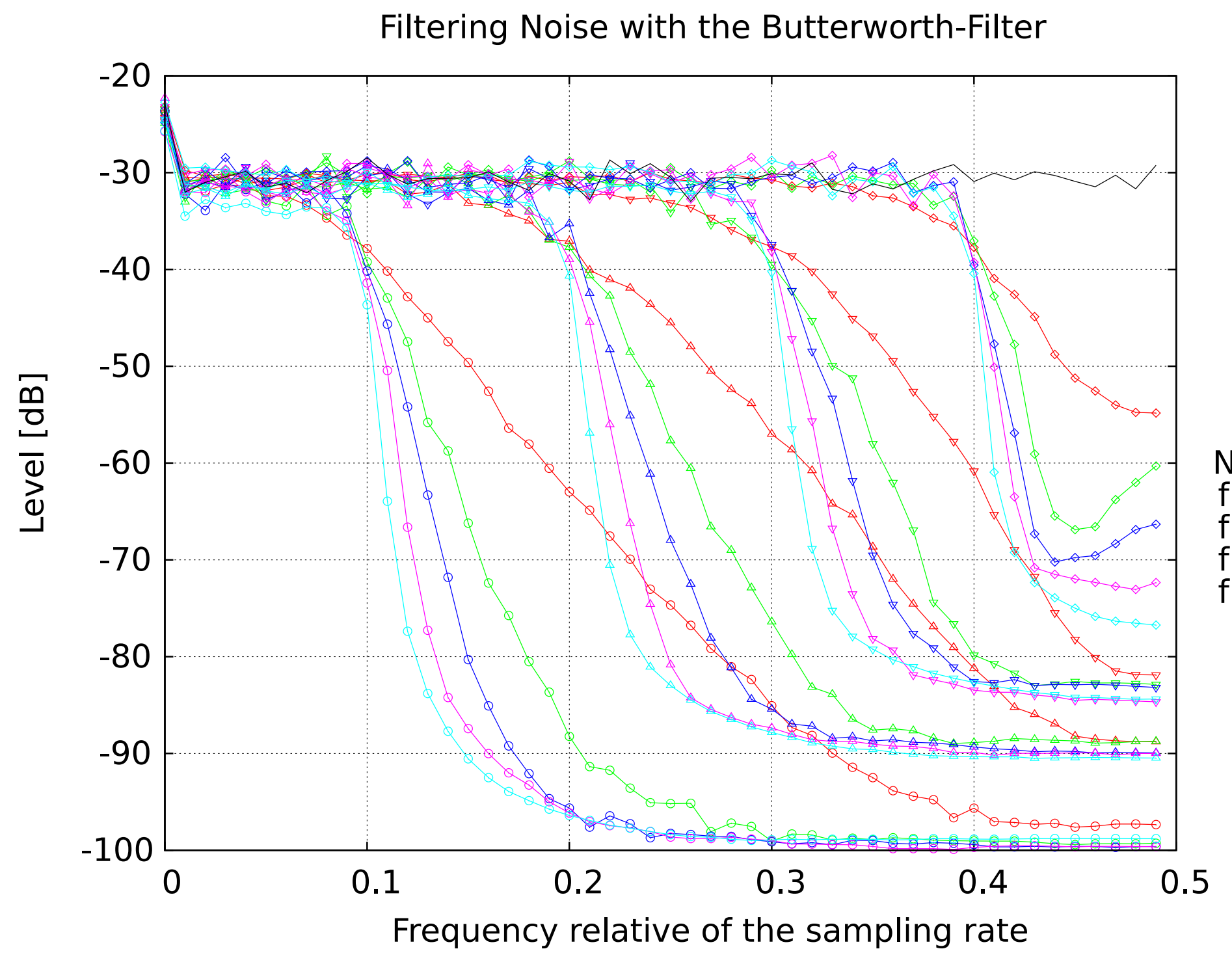

Figure 3: Timing Resolution with simulated 4GS/s

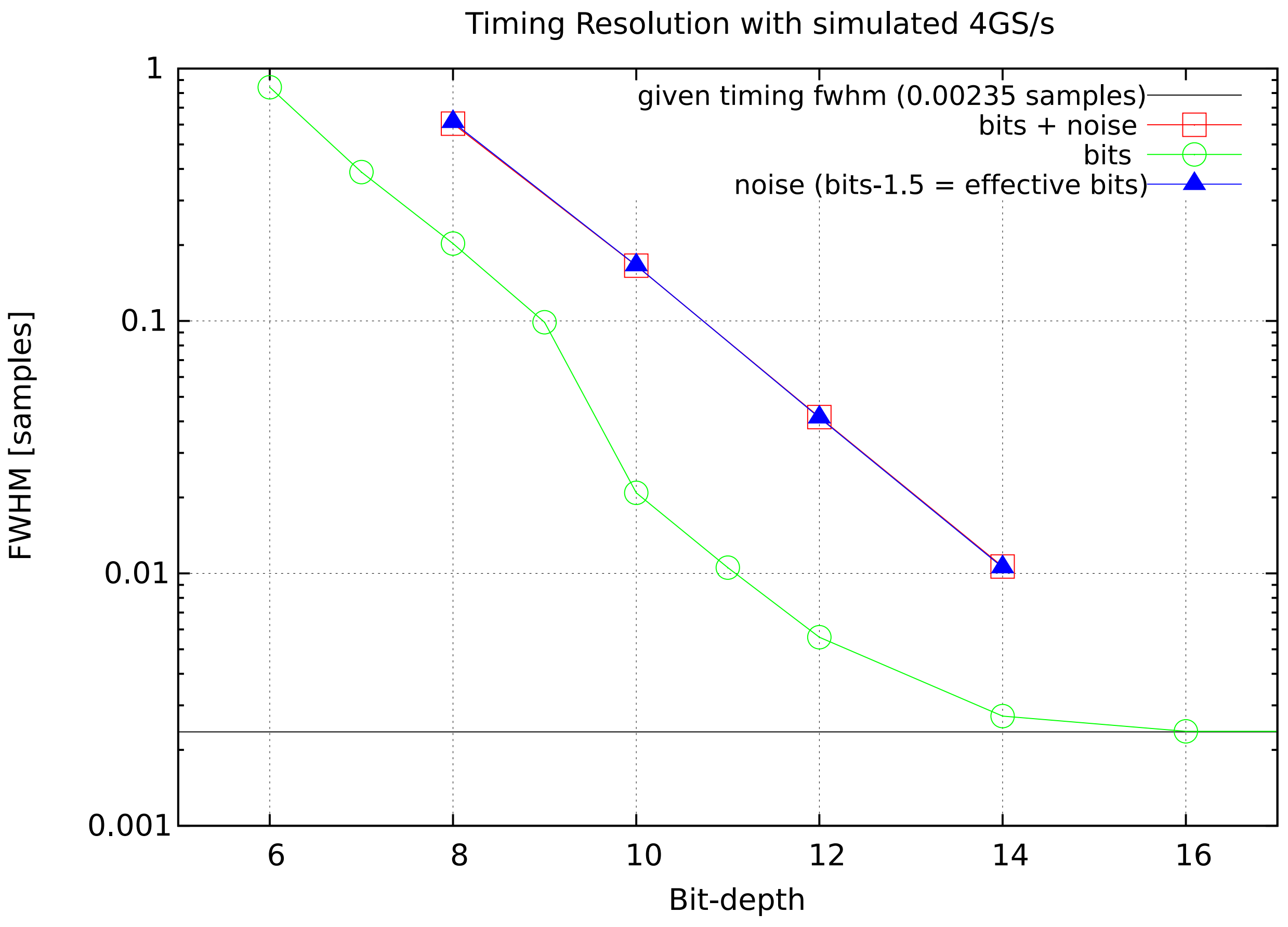

Figure 4: Improvement with Lowpass-Filtering

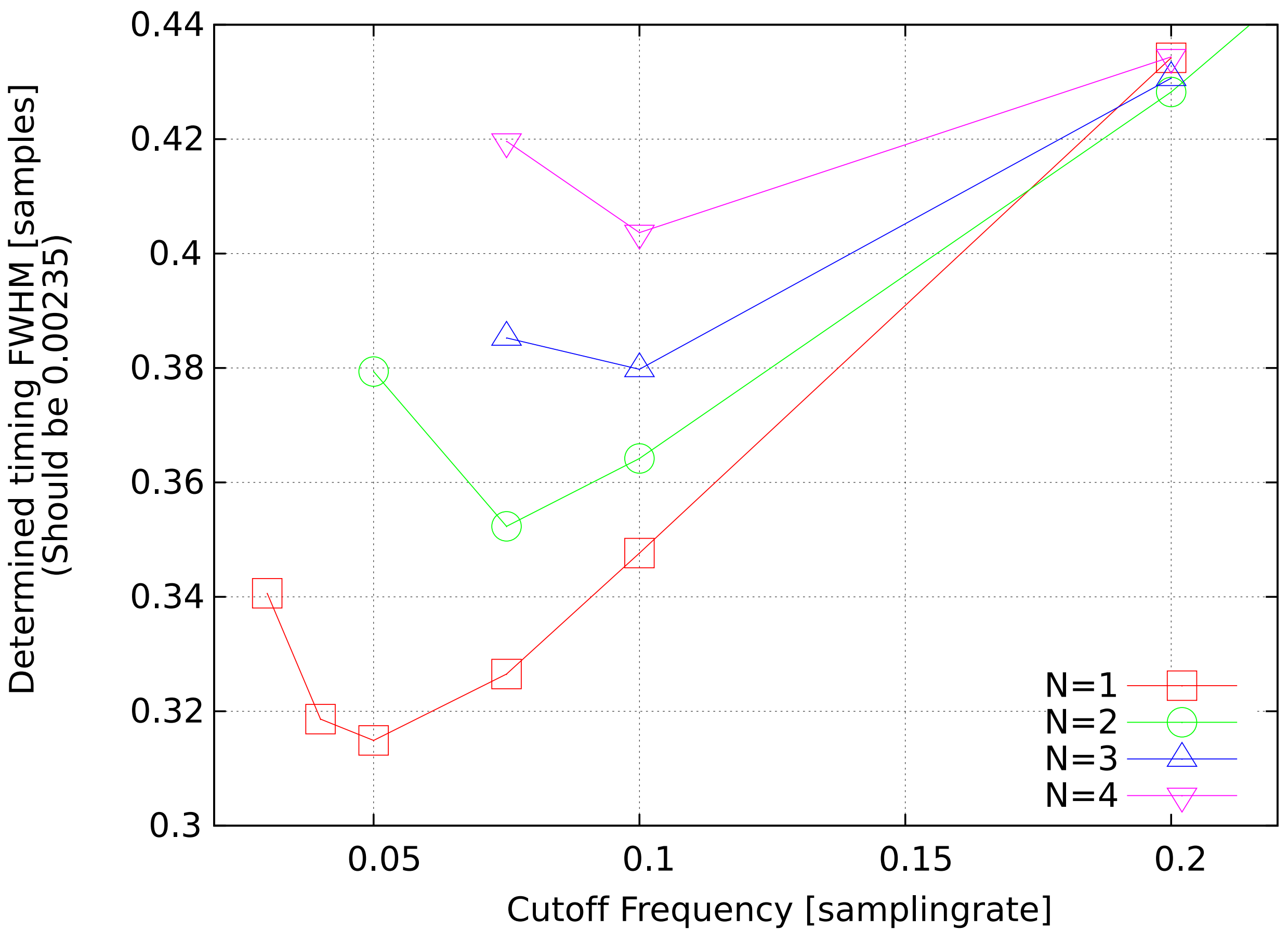

Table 1: Comparing the results

Method	Relative Timing FWHM [samples]	4GS/s "real" FWHM [ps]
Vertical quantization only (8 bit)	0.202 samples	50 ps
Noise of effective 6.5 bit	0.612 samples	153 ps
Butterworth-Lowpass f=0.05 N=1	0.314 samples	75 ps

Simulated 4GS/s Digitizer

The first error-source to investigate is the vertical quantization, the bit-depth. The green circles in figure 3 shows the determined timing resolutions for various bit-depths. Given was a timing distribution with 0.00235 samples fwhm. It is clearly shown that higher bit-depths give better timing resolutions (with the same sampling-rate). Calculating this to a 4GS/s digitizer gives ~50ps FWHM with 8-bit and ~5.2ps FWHM with 10-bit resolution.

As the datasheets for (at least) Acqiris digitizers state only an effective bit-depth of 1.5 bits less than the real bit-depth due to noise, the next simulations done where a) with vertical double resolution and noise of the right level and b) reduced bit-depths and the according noise-levels combined. The blue triangles in figure 3 show the results of just the added noise, while the red squares are noise + bit-depth. These two show no real difference which makes the noise added from the digitizers analog electronic (pre-amps and converters) the main source for the limited timing resolution. Computed to real 4GS this gives 152ps FWHM with 8-bit (6.5 effective bit) and 41ps for 10-bit (8.5 effective bits).

Less Noise with Lowpass Filter

To reduce the noise, one of the best options is to apply a lowpass filter on the raw data. A butterworth-filter from literature was used for these tests. Given an input of white noise figure 2 shows the frequency response of the filter for various cutoff-frequencies and filter orders. The frequency is used relative to the samplingrate which makes the implementation of the filter-module independent of the digitizer used. Figure 1 shows in the lower row the effect of the filtering on the pulses compared to the original above.

Figure 4 shows the timing resolutions determined at different cutoff frequencies and filter orders (N). All the simulations where done with double-resolution and added noise of 6.5 effective bits. Clearly the timing resolution is better then without the filtering. The best resolution with N=1 and f=0.05 evaluates to 75ps for a 8bit-4GS/s-digitizer. Compared to without the filter, this is an improvement of ~2 in the timing resolution.

Conclusion

The main source for the bad timing resolution seems to be the noise reducing the bit-depth, especially in the 8-bit digitizers. It is pretty clear, removing the noise from the sampled data improves the timing resolution. We found that applying lowpass-filters from the dsp-world gives good results.

Table 1 shows the three best resulting timing resolutions compared to each other for clearity.

References, Acknowledgements

[Nissila2005] J. Nissilä et al. Performance analysis of a digital positron lifetime spectrometer. Nuclear Instruments and Methods in Physics Research A, 538:778-789, 2005

[Aavikko2005] R. Aavikko et al. Stability and performance characteristics of a digital positron lifetime spectrometer. ACTA PHYSICA POLONICA A 107, 2005

[EPOS] http://positron.physik.uni-halle.de/EPOS/Software

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