ANALOG + PHOTON COUNTING

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ABSTRACT. The algorithm for combining analog and photon counting data (gluing) is described. A discussion when the signals need to be combined is followed by stepwise procedure to do this with real data.

1. INTRODUCTION

The Licel transient recorder systems have a parallel analog and photoncounting detection chain. The combination of both signals gives the high linearity of the analog signal for strong signals and the high sensitivity of the photon counting for weak optical signals. The integration of both detection mechanism into a single device avoids ground loops and other problems that make the combination otherwise cumbersome. The main idea of the signal combination is that there is a region where both signals are valid and have a high signal to noise ratio. For typical Mini-PMT that region extends from 0.5 to 10 MHz in the photon counting. To combine (glue) both signals, the photon counting needs a dead time correction. There are two typical deadtime scenarios, while the Licel photon counter can be best described as nonparalyzable.

2. PARALYZABLE SYSTEM

$$N = S\exp(-S\tau_d)$$

Where:
N - is the observed countrate
S - is the true countrate
τ_d - is the system dead time

3. NONPARALYZABLE SYSTEM

(1) $$N = \frac{S}{1 + S * \tau_d}$$

N - is the observed countrate
S - is the true countrate
τ_d - is the system dead time

While the paralyzable case is nonlinear equation, the nonparalyzable case can be easily inverted to

(2) $$S = \frac{N}{1 - N * \tau_d}$$

As both cases are only a theoretical model, they are valid for lower countrates but fail when $S * \tau_d$ becomes larger than one. From a numerical point of view Eq. 2 can be only applied to a signal as long as

(3) $$N < \tau_d$$

As an example the correction factor for a time constant of 4ns and a observed count rate of 5 MHz is 1.02. As typical averaged maximum observed countrate is 160MHz the correction factor would be 2.77. This would imply an maximum count rate of 470MHz. The glued profiles however show a virtual countrate in the 2GHz region for a 20mV peak.

4. THE GLUEING ALGORITHM

In the valid region of both signals between the lower toggle rate (typical 0.5MHz) and the upper toggle rate (typical 10MHz) one seeks the linear regression coefficients to transfer the analog data into photon counting data:

$$\sum_{i=1}^{n} (PC(z_i) - (a * Analog(z_i) + b))^2 = min \tag{4}$$

The coefficients a and b are applied to the analog signal and above the upper toggle rate the scaled analog is used and below the photon counting data.

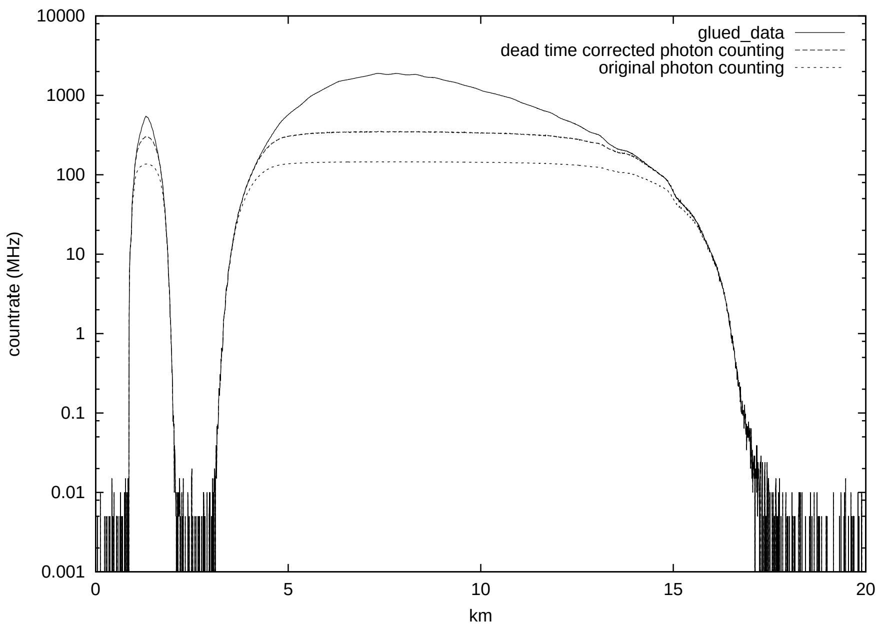
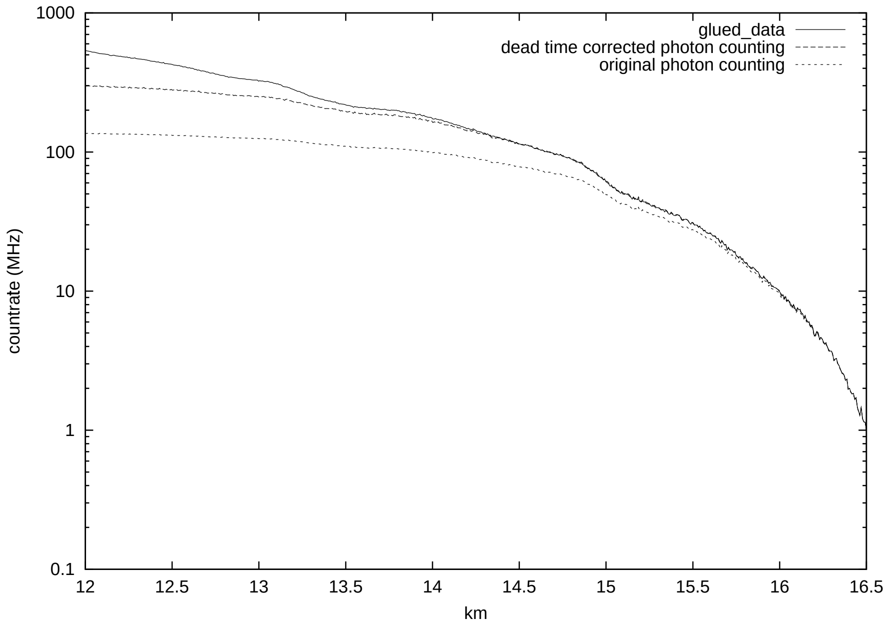


FIGURE 1. Glued data

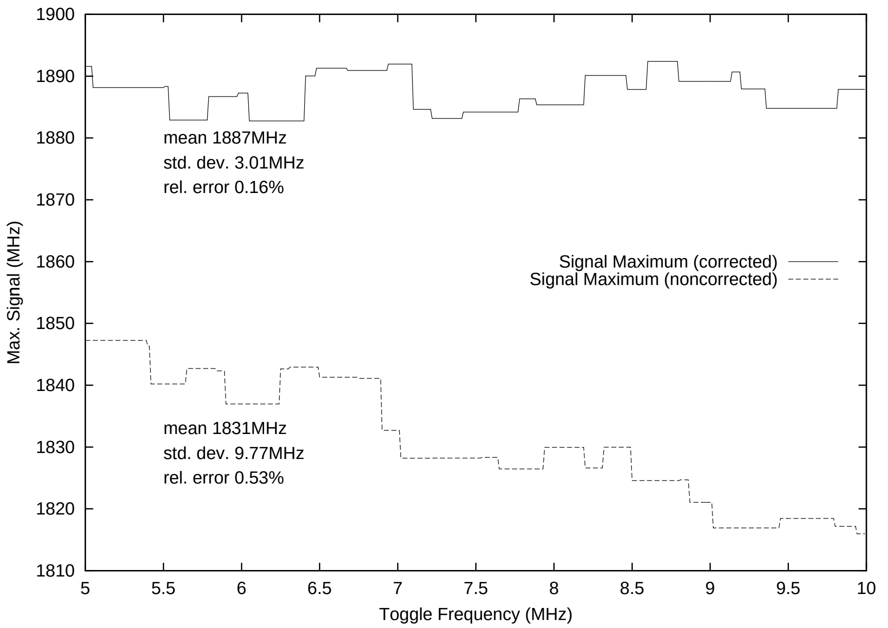
The zoomed plot shows that the dead time correction function is valid up to 130 MHz.



Zoomed plot

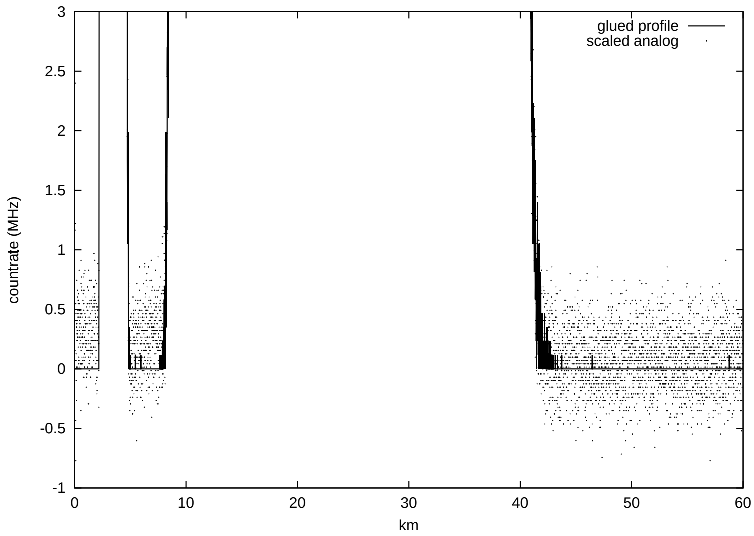
If one varies the upper toggle frequency between 5 and 10 MHz the standard deviation for the signal maximum is only 3MHz or 0.1%. This proves the numerical stability of the proposed algorithm.

The figure below shows the necessity of applying the dead-time correction first. Without correction the signal maximum becomes stronger dependent from the max. toggle rate.



Signal maximum for different max. toggle frequencies without dead-time correction

Figure 4 demonstrates the advantages of the photon counting in the low light level region. While the analog signal shows the noise coming from the ADC, the photon counting is still able to follow the input signal and extends the dynamic signal range from the analog signal by another 2 orders of magnitude.



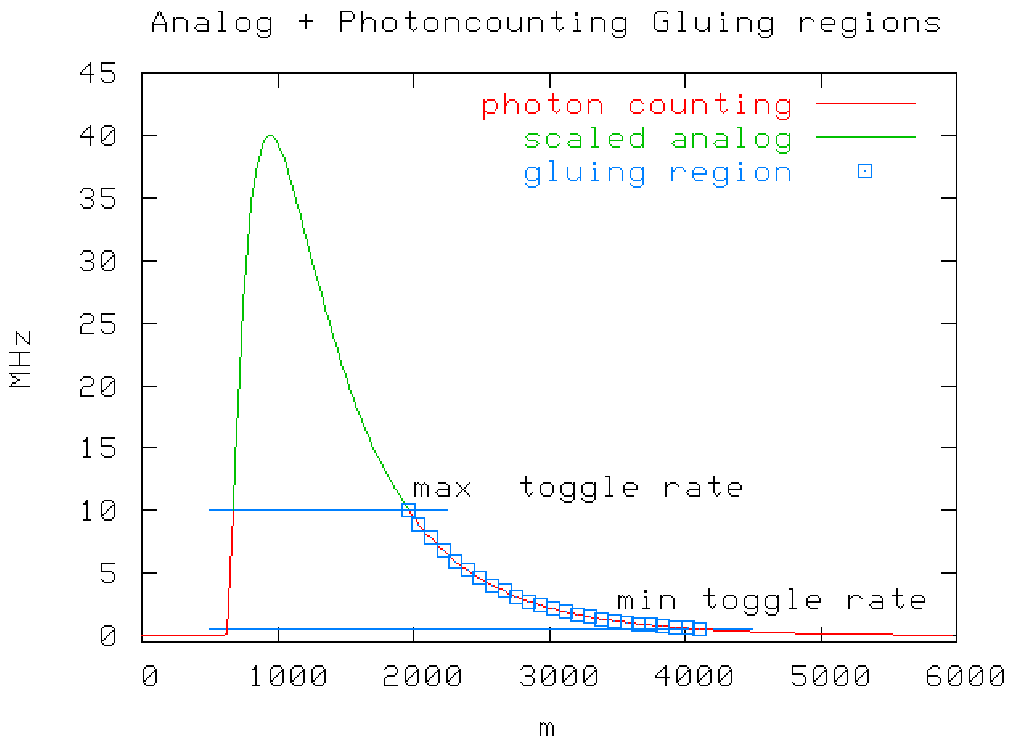
Increased dynamic range under low light level conditions

5. Gluing strategy

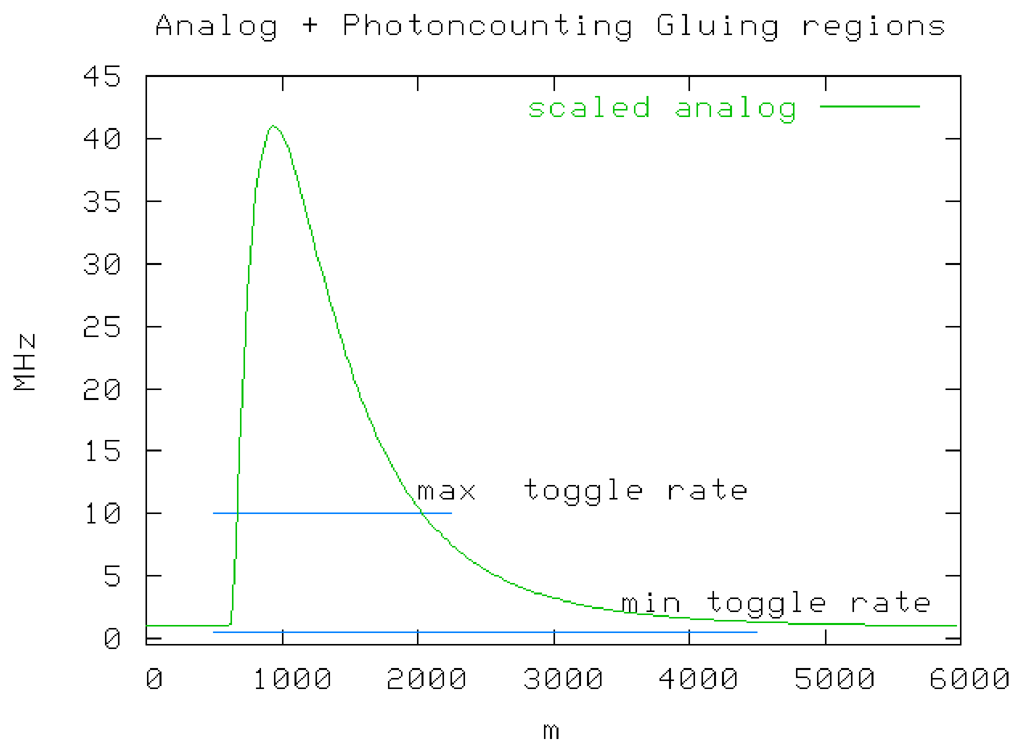
In principle one should glue two signals only if it is necessary. The only scenario when one really need to glue is when:

(1) the peak value of the deadtime corrected photon counting is above the maximum toggle rate and
(2) the background of the deadtime corrected photon counting is below the minimum toggle rate.

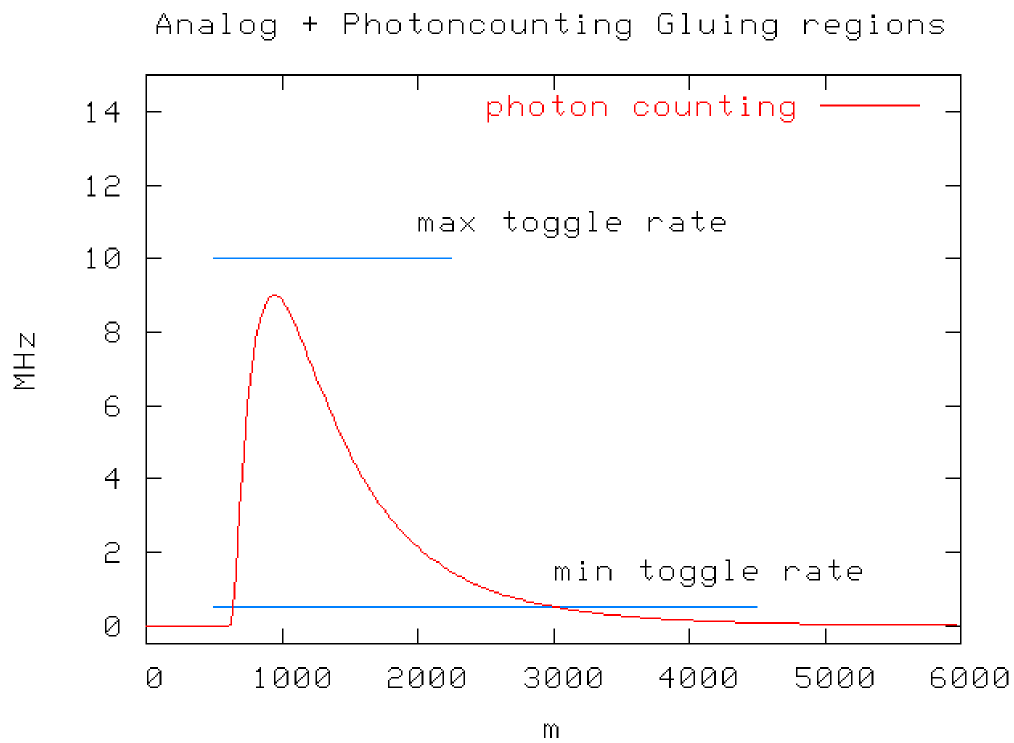
This situation is shown below:



If one assumes that the analog is valid enough to compute a regression curve then there is no need to compute a regression if the photon counting background exceeds the minimum toggle rate. In this case one can use the scaled analog.



If the peak countrate does not exceed the max. toggle rate there is no need to glue either and the deadtime corrected photon counting should be used.



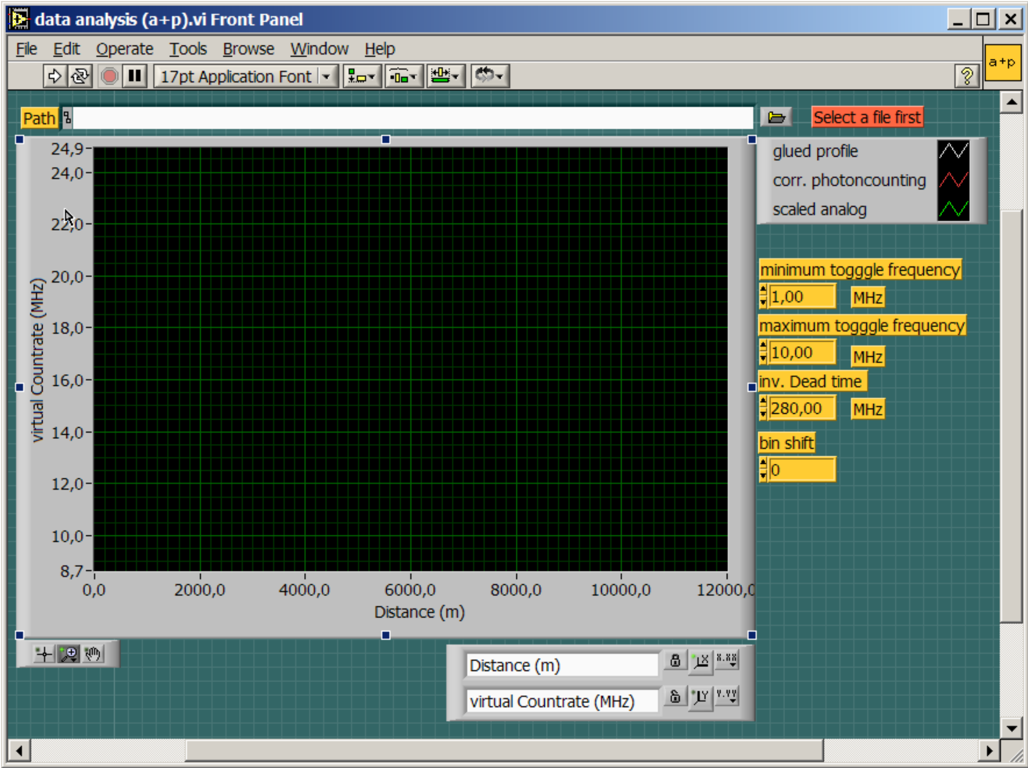
The use of a glued profile instead of a pure photon counting profile if the peak value is only slightly above the max. toggle rate. say at 12 MHz for 10MHz max. toggle rate could also be avoided.

6. Tutorial

Licel provides a sample code in LabVIEW for combining analog and photon counting data. The sample code assumes that the provided data has been previously recorded with the Acquis Software. One needs a LabVIEW license to look into the code. Reuse of this code in your projects is desired and permitted.

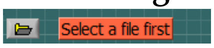
6.1. Loading the VI.

Please open the `data analysis (a+p).vi` from the `Postan.llb`.



6.2. Selecting a data file.

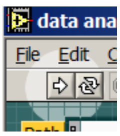
Click first the browse button



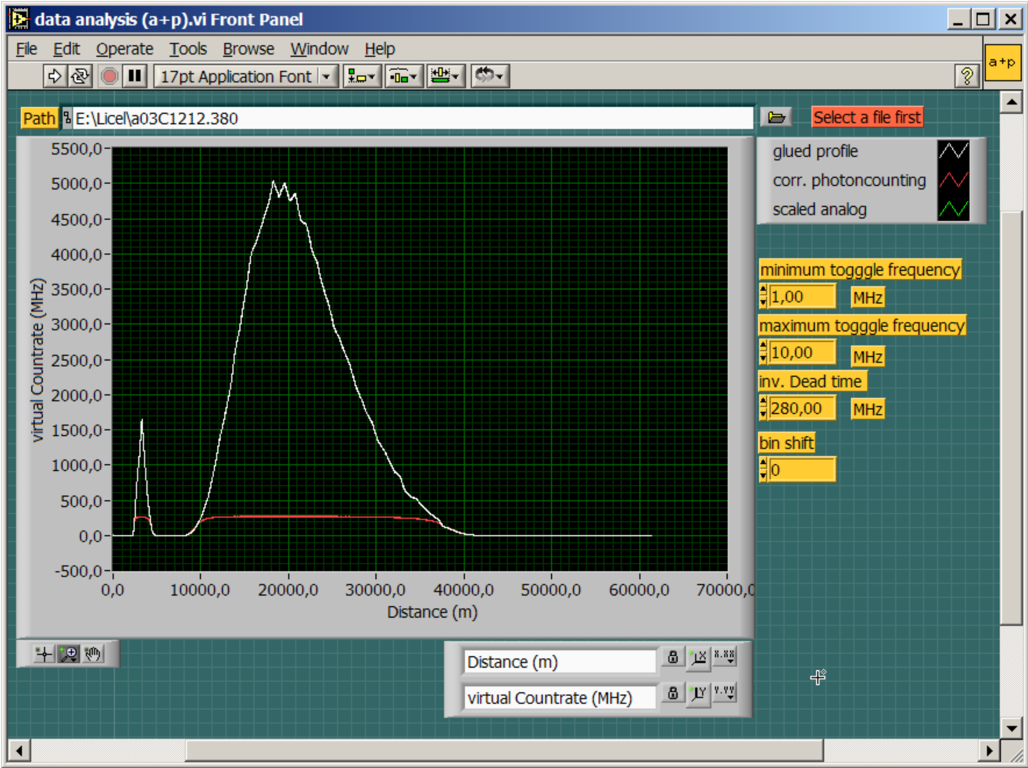
in the upper left part of the vi and select a data file that has previously been recorder with the Acquis-Module. At `http://www.licel.com/download/gluetestfile.zip` one can find the data file which has been used for this demonstration.

6.3. First Run.

Press the run button in the upper right corner



and one should see the following curves

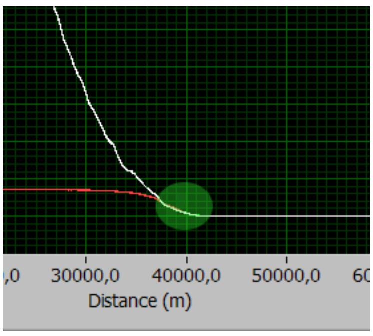


The white curve shows the combined signal.

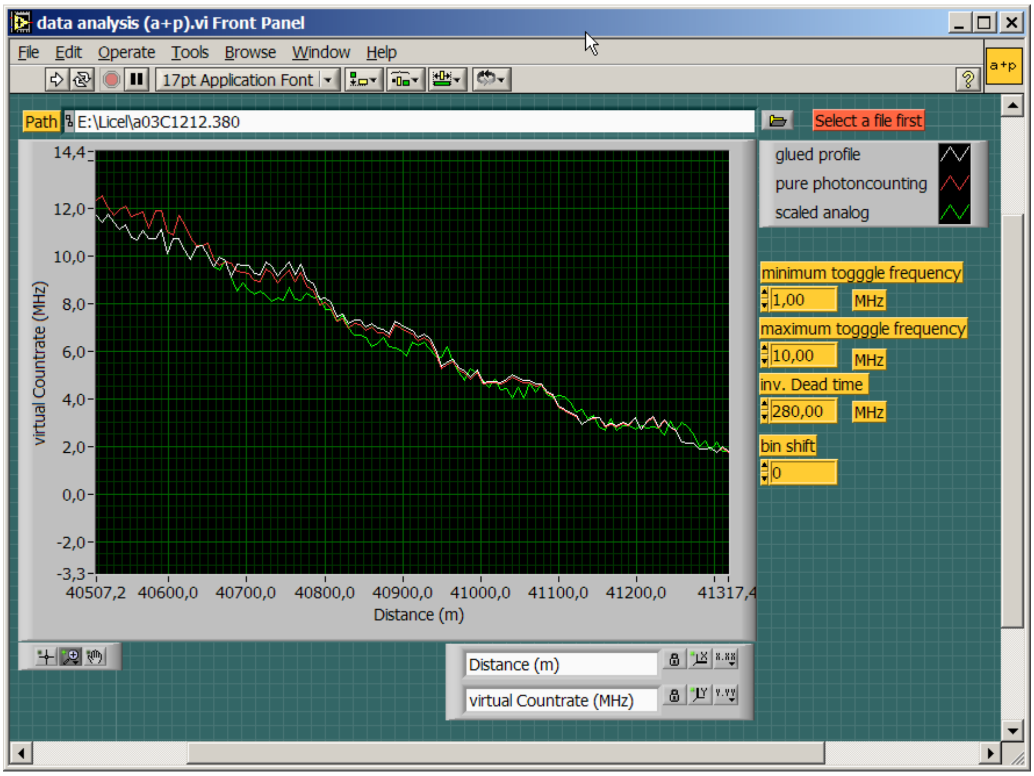
6.4. **Bin shift.** The analog and the photoncounting data has a fixed shift between them. This is a result of two factors

(1) Analog Bandwith, the preamplifier contains a antialias filter which has a bandpass of half the sampling frequency this delays the analog signal with respect to the photon counting by 2 bins
(2) ADC pipelining, modern ADCs sample the voltage in a multiple step process so that the sample result will be available several clock cycles later after the actual sampling took place.

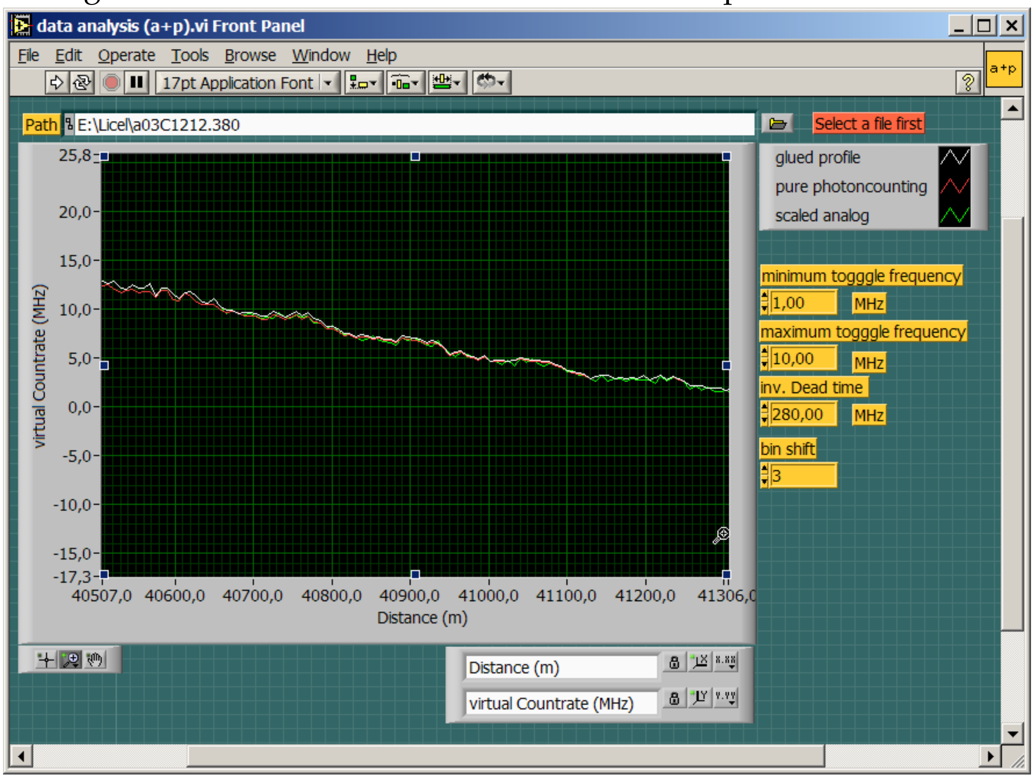
To demonstrate this zoom into the profile



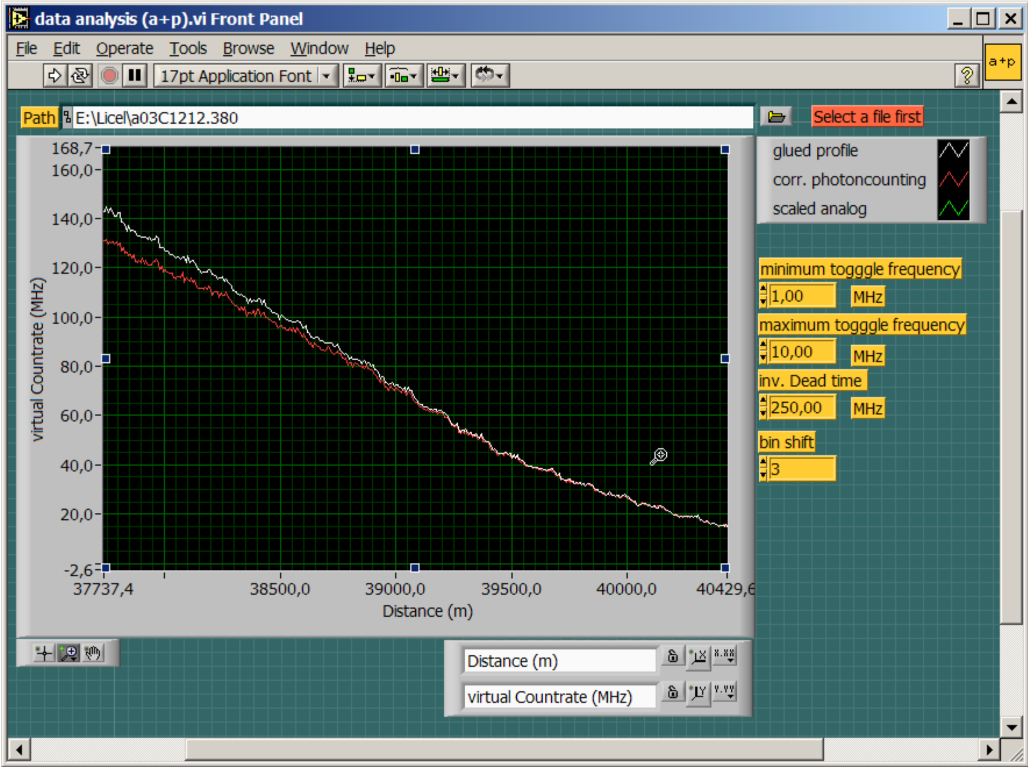
There is a shift of the scaled analog signale versus the photon counting data (the green vs. white curve)



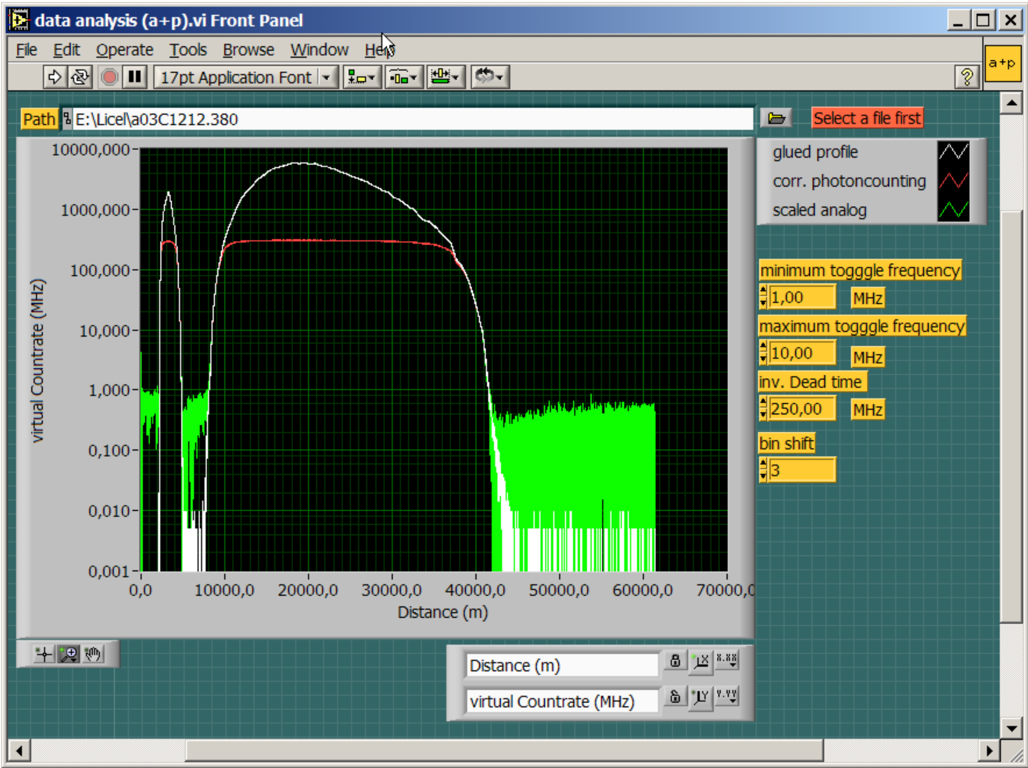
Setting the bin shift to 3 will result in a much more perfect match.



6.5. **Photon counting deadtime correction.** The default value of 280MHz is rather conservative approach for the deadtime correction. Lowering this value increases the deadtime correction. In the region above the max toggle rate a perfect deadtime correction will show a longer region where the glued curve and the deadtime corrected photoncounting coincide.



6.6. **5 Orders of magnitude.** Changing the y-scale from linear to logarithmic reveals the potential of this signal combination.



The red curve shows that the photon counting becomes nonlinear and saturates. The green curve shows that signals which are close to the analog baseline are difficult to distinguish. But the combination of both signal prevents the nonlinearity for strong signals and gets the good baseline from the photon counting.

6.7. **Next steps.** Code similiar to `data analysis (a+p).vi` needs to be integrated into the data retrieval software. Experience shows that recording background file without a laser signal and substracting the averaged background from real signals will improve the analog background flattness and give more consistent gluing results. Once the transfer coefficients are found one could use them instead of searching in every signal for a new set of coeefficients. The coefficient should stay constant if the detector has the same applied high voltage.

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