Time walk compensation of an Avalanche photo-diode with a linear photo-detection

E. Samain, R. Dalla
OCA 2130 route de l'observatoire, 06460 Caussols, France,
Etienne.samain@obs-azur.fr tel (33) 4 93 40 54 29

Ivan Prochazka
Czech Technical University in Prague, Brehova 7 115 19 Pragues Czech Tepublic
prochazk@mbox.cesnet.cz

Abstract
The photodetection in the Geiger mode appears promising because of the time stability, the sensitivity, and the simplicity of the device. The transit time between the pulse arrival and the moment when the signal reaches a given detection threshold depends on the photon number in the light pulse. A precise knowledge of this photon number permits to eliminate this time walk if a correction table is known. A device using an auxiliary linear light sensor to measure this photon number coupled with a photo-diode in the Geiger mode for the timing purpose is presented here. This device is designed for both the space and ground segment of the T2L2 [1, 2] (Time Transfer by Laser Link) experiment and could be used in the framework of the satellite laser ranging activities.

1. Introduction.

The transit time between the light pulse and the electrical response of an avalanche photodiode in the Geiger mode is determined by a reliable exponential growth of electron and hole populations[3, 4]. In particular, this transit time depends on the photon number in the light pulse. If the law between this time walk and the photon number impinging the Geiger photo detector is known, an evaluation of this photon number would permit to subtract this time walk and to get a time response that does not depend on the light level [5]. A device, using an auxiliary linear light sensor to measure this photon number, coupled with a photo-diode in the Geiger mode for the timing purpose has been designed.

The figure 1 shows the typical time walk and the typical precision rms of an avalanche photo-diode in the Geiger mode versus the photon number.

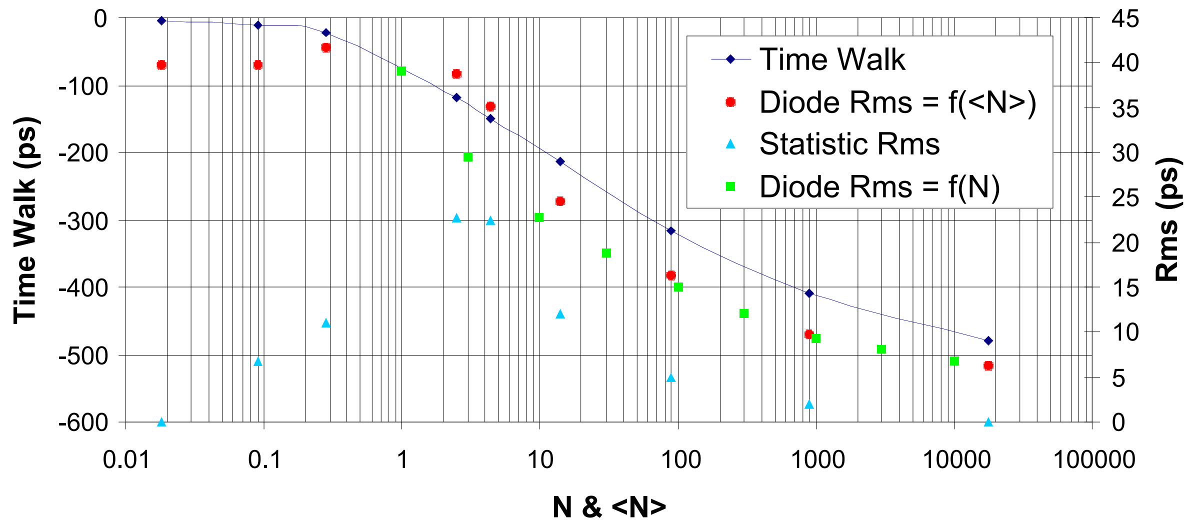

Figure 1 : Time walk and precision rms of an avalanche photo-diode (Silicon Sensor AD230) in the Geiger mode versus the photon number N and <N>.

2. Principle

The measurement principle is to split the light beam in two parts with a beam splitter and to use one part for the photon number determination and the other for the timing. The photon number determination is performed with a linear photo detector (an avalanche photo-diode in the gain mode or photomultiplier tube) linked with an analog to digital converter. The photo number measured by the linear photodetector can only give an evaluation of the photon number impinging the Geiger photo detector. Then, due to the time walk of the Geiger detector, this photo number uncertainty introduces a time uncertainty.

The figure 3 shows this uncertainty which has been computed by the Bayle formula. The figure shows also the intrinsic uncertainty of the Geiger diode (SSO AD 230) and demonstrate that the statistical uncertainty has to be consider if the photon number is low. It becomes negligible as compared to the Geiger diode uncertainty as soon as the photon number is greater than 30.

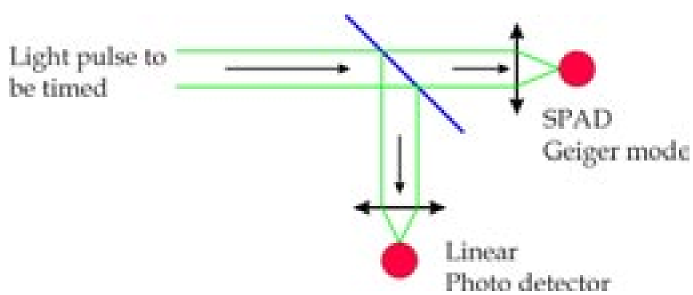

Figure 2 : Principle

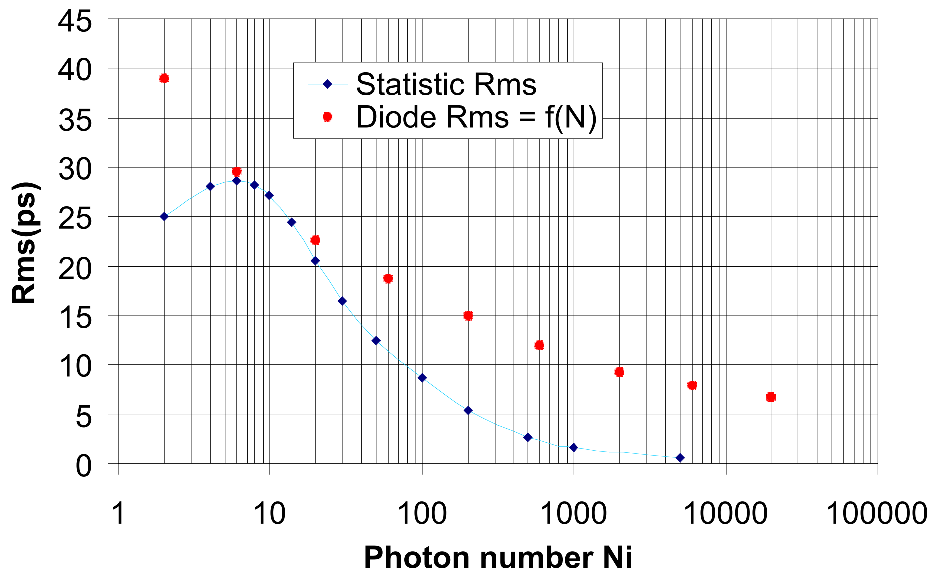

Figure 3 : Statistical uncertainty and intrinsic uncertainty of the Geiger diode (SSO AD 230).

The instrument is designed both for a space application (in the framework of the T2L2 project) and also for a ground application. The synoptic of the space instrument and the ground instrument are respectively shown on figure 4 and 5. The space application requires an asynchronous photo-detection mode since the time arrival of the light pulses cannot be predicted. This is achieved by using the signal coming from the linear photo-detector to build the bias signal above the breakdown voltage of the Geiger diode (non linear photo-detection).

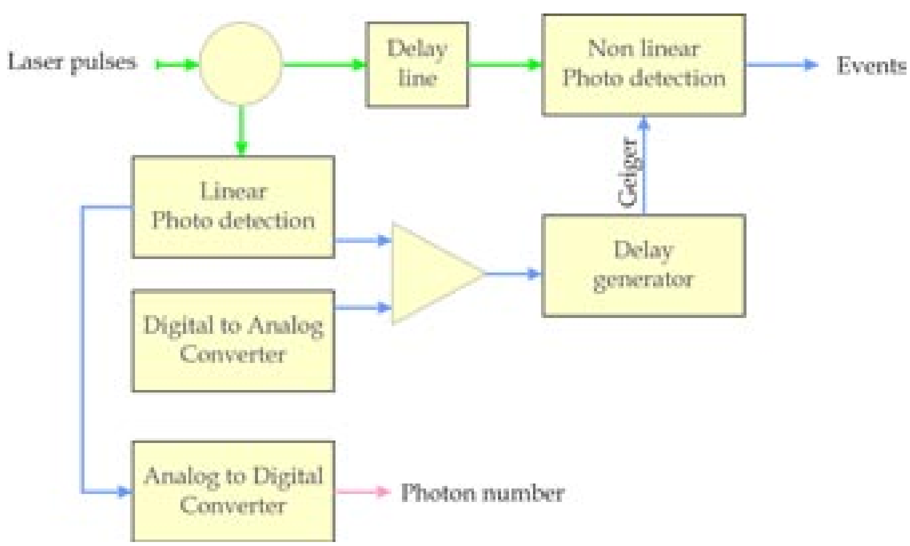

Figure 4 Synoptic of the space instrument

3. Prototype.

The photography presented in figure 6 is the prototype of the instrument. The linear photodetection is performed with an RCA 902S Avalanche photodiode in the Gain mode linked to an integrator amplifier. The integration time of the integrator is tuned in order to relax the band width specifications of the analog to digital converter. The minimum threshold of this linear channel is in the range of 100 photon-electrons and the dynamic is 10^4. The analog to digital converter operates with dynamic of 16 bits and an input bandwidth of 200 MHz. It has a linearity error of 1.3 bits rms and a precision of 1.3 bits rms.

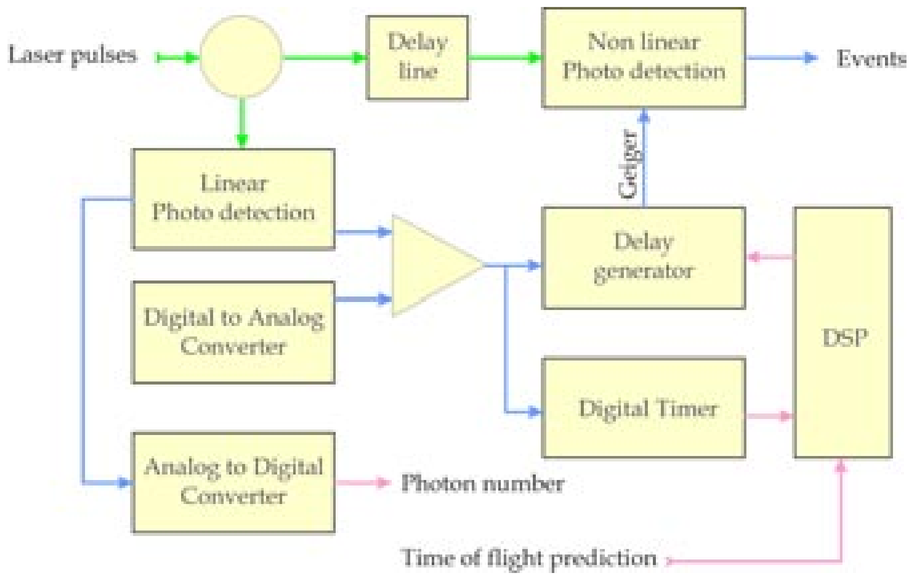

Figure 5 : Synoptic of the ground instrument.

As compared to the space instrument, a time filtering is added.

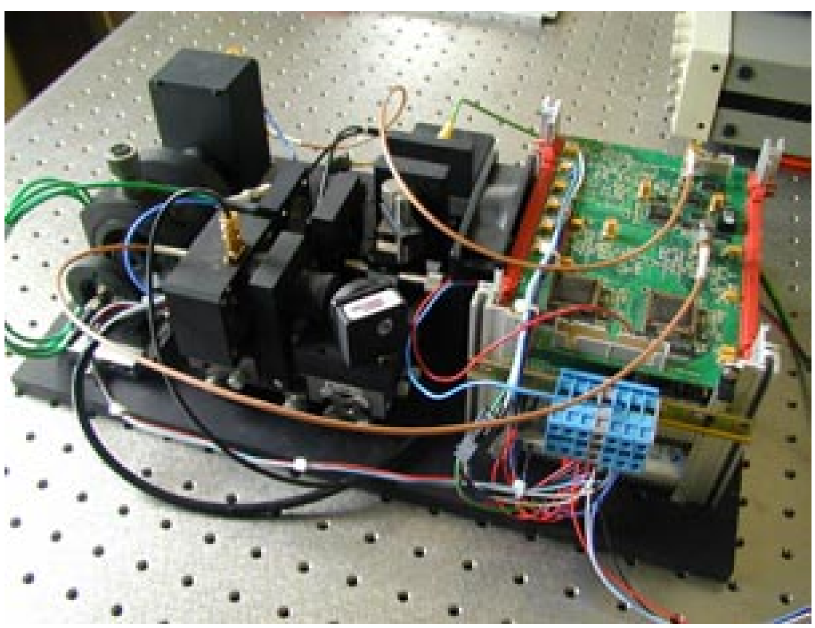

Figure 6 : Prototype

The Geiger avalanche photo-diode used for the timing purpose is a Silicon sensor chip, ref : SSO AD230. It has a diameter of 230 µm and a breakdown voltage of 150 Volts. The temperature of the chip is controlled with a Peltier module. The bias voltage above the breakdown is 150 volts, so that the global voltage applied to the diode to detect photons is 300 volts. The response of the Silicon sensor diode in a single photon mode is shown on figure 7. The precision in this mode is better than 40 ps.

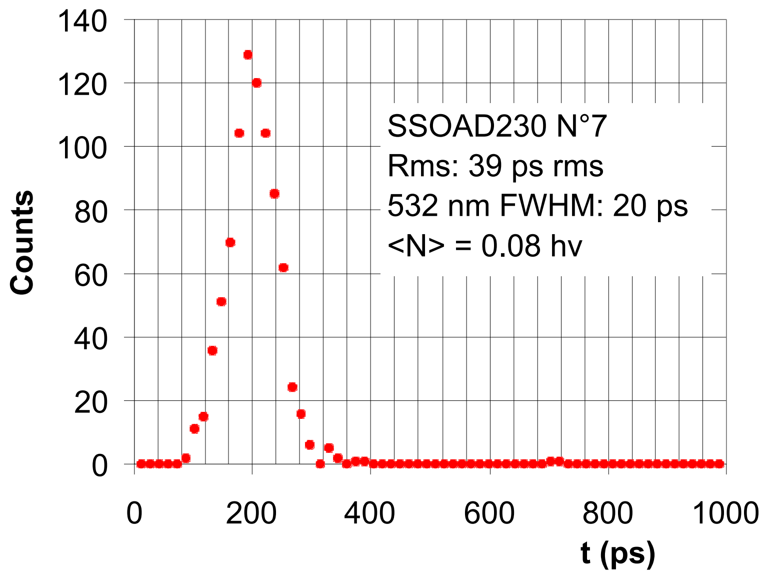

Figure 7 : Response of the Silicon sensor diode in a single photon mode.

Laser pulse width : 20 ps @ 532 nm.

4. Results

The figure 8 shows the time walk and the precision versus the photon number of the overall instrument. The instrument is working in an asynchronous mode with a Geiger signal (to bias the Geiger diode) built from the linear detector. A delay line made with a 3 m length optical fiber permits to bias the Geiger diode just before the arrival of the light pulse. The Geiger diode is a silicon Sensor AD230.

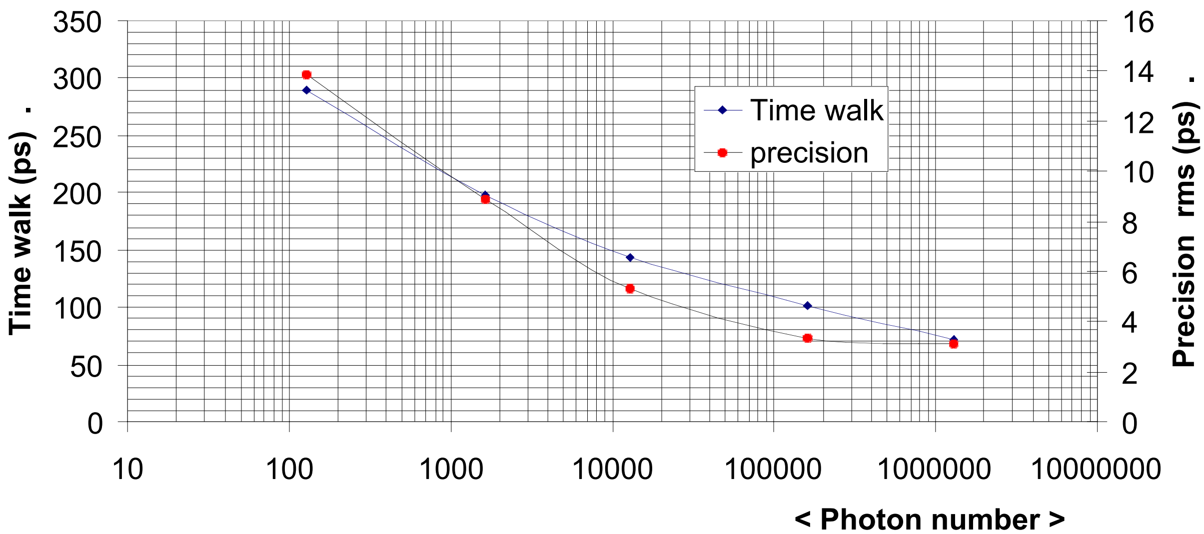

Figure 8 : Time walk and precision versus the photon number of the global instrument.

In order to evaluate the time stability of the instrument some continuous measurements are made during a few hours. A first class of measurement, obtained with a YAG laser @ 10 Hz, permits to computed the long term stability (figure 9) and a second class, performed with a laser diode @ 1 kHz, the short term stability (figure 10).

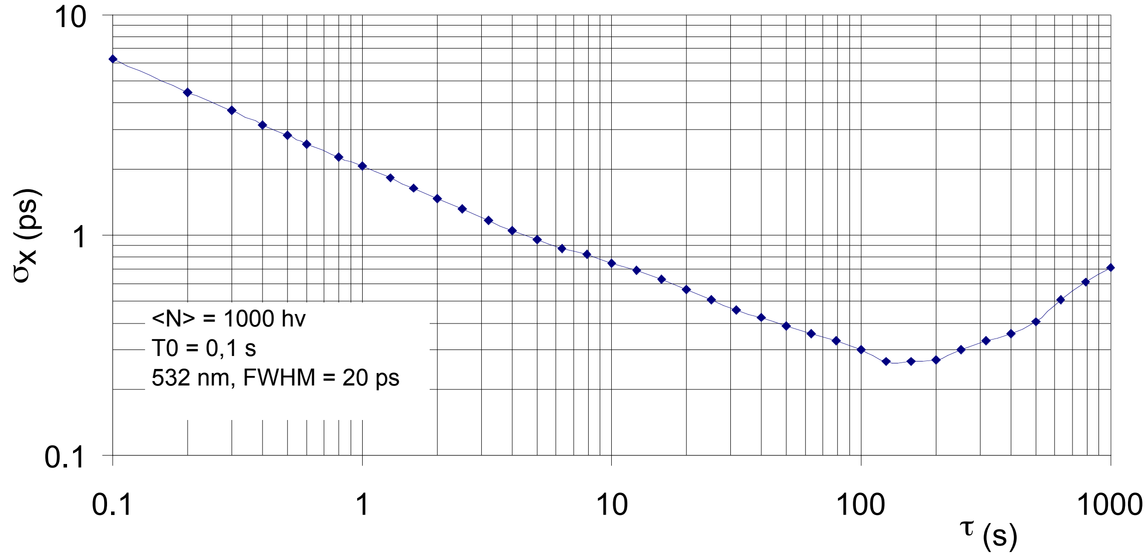

Figure 9 : Long term stability performed with a YAG Laser @ 10 Hz.

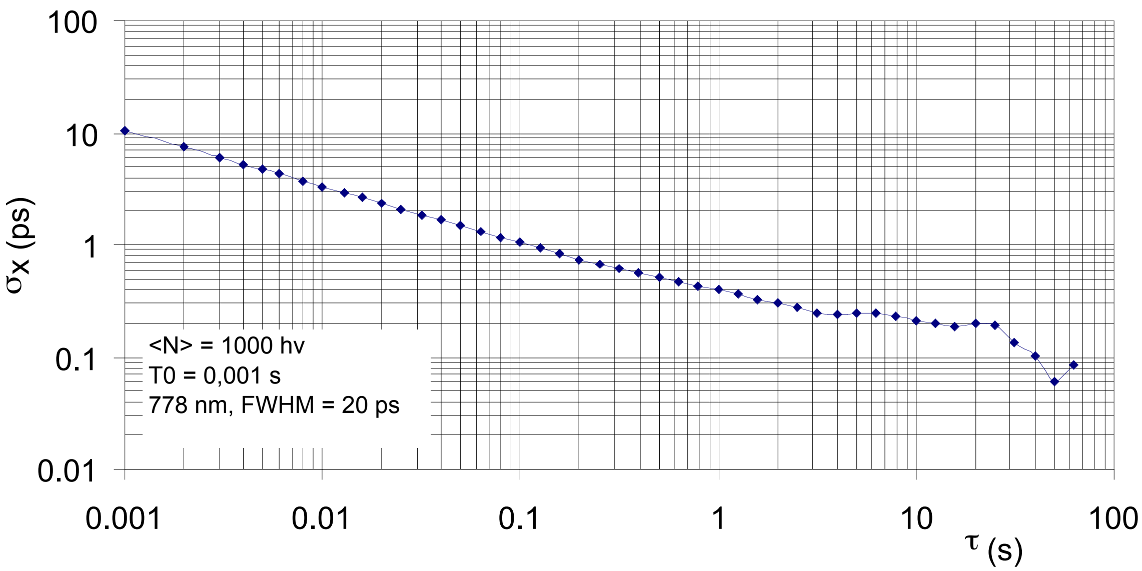

Figure 10 : Short term stability performed with Laser diode @ 1 kHz.

These graphs show a very good time stability with a floor in the range of a few tenth of picoseconds.

5. Prospective and conclusions

The global specifications of the instrument are :

- Light level dynamic ~ 10^4
- Precision : between 2 ps and 20 ps rms (depending on the light level)
- Time Stability : < 1 ps over 1000s
- Insensitive to the laser pulse width (20 ps – 200 ps)
- Asynchronous detection mode

Some other measurements have been made by replacing the Silicon Sensor Avalanche photodiode by a SPAD based on the process K14. This chip has been designed by the Czech Technical University [6]. The main characteristics of the component are :
- Process : K14
- Diameter : 100 µm
- BreakDown Voltage : 30 V

The performances of the photo-diode in a single photon mode are shown on the figure 11. The precision is 21 ps rms and the distribution is quite symmetrical with only a slight tail.

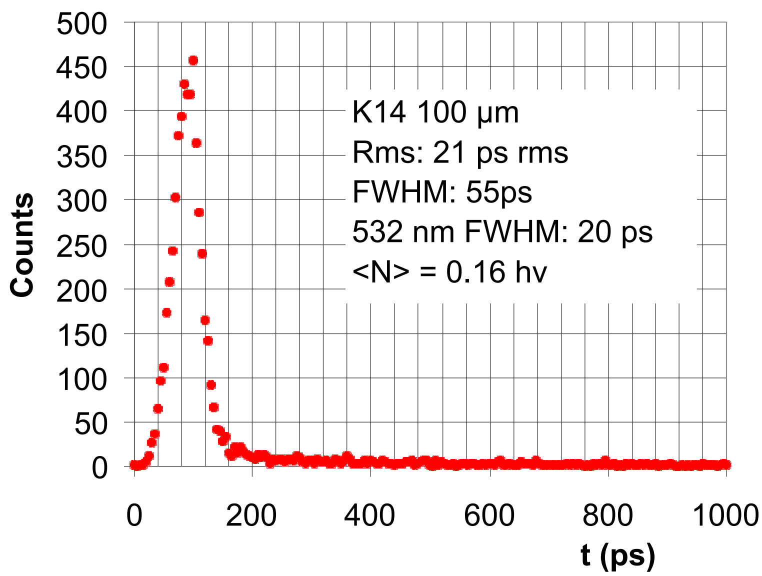

Figure 11 : Performances of the SPAD K14 100µm in a single photon mode.

To evaluate the center-edge effect of the photo-diode, measurements have been made with a small spot focused on the chip (figure 12). The spot was produced from a single mode optical fiber in order to be able to produce a spot size smaller than 5 µm. The figure 12 shows a time walk and a precision quite constant over the 70% of the diode diameter while the relative efficiency is constant over the whole surface.

The figure 13 shows the time walk and the precision of the diode in a multi photons mode. The bias voltage above the break-down is 7 Volts. This bias, which is a relatively high voltage for this diode, permits to decrease the time walk of the diode and then to decrease the statistical error introduced by the compensation used in our instrument (figure 3). The time walk measured is 55 ps per decade which is two time lower than the time walk measured with the silicon Sensor component. The precision in the multi-photon mode is also very interesting with 1.5 ps rms @ 10000 photons. At the end, this SPAD K14 photo-detector, will permit to increase the performances of the global instrument as compared to the performances we get with the Silicon Sensor photo diode.

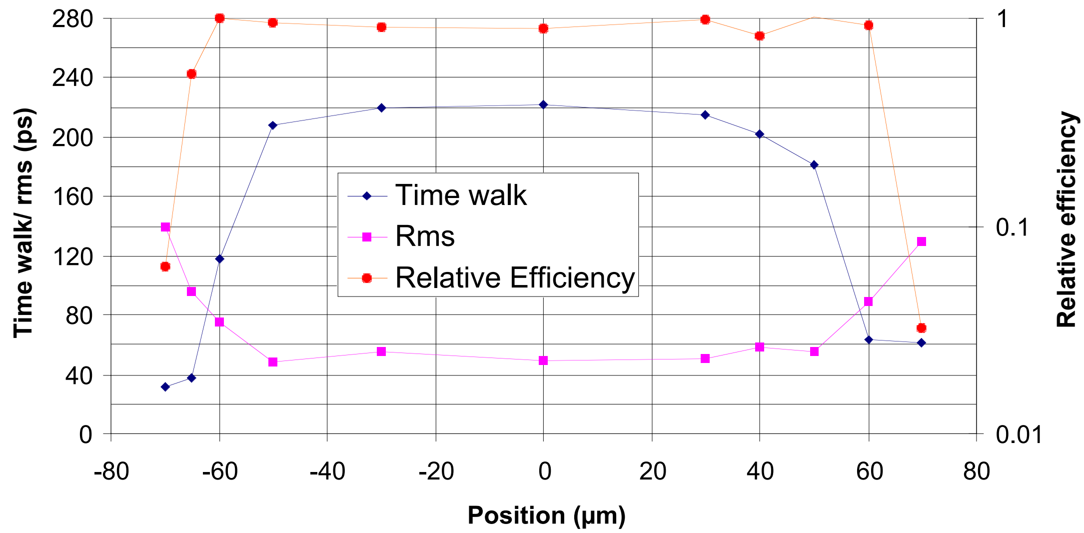

Figure 12 : Center-Edge effect of the SPAD K14 100 µm.

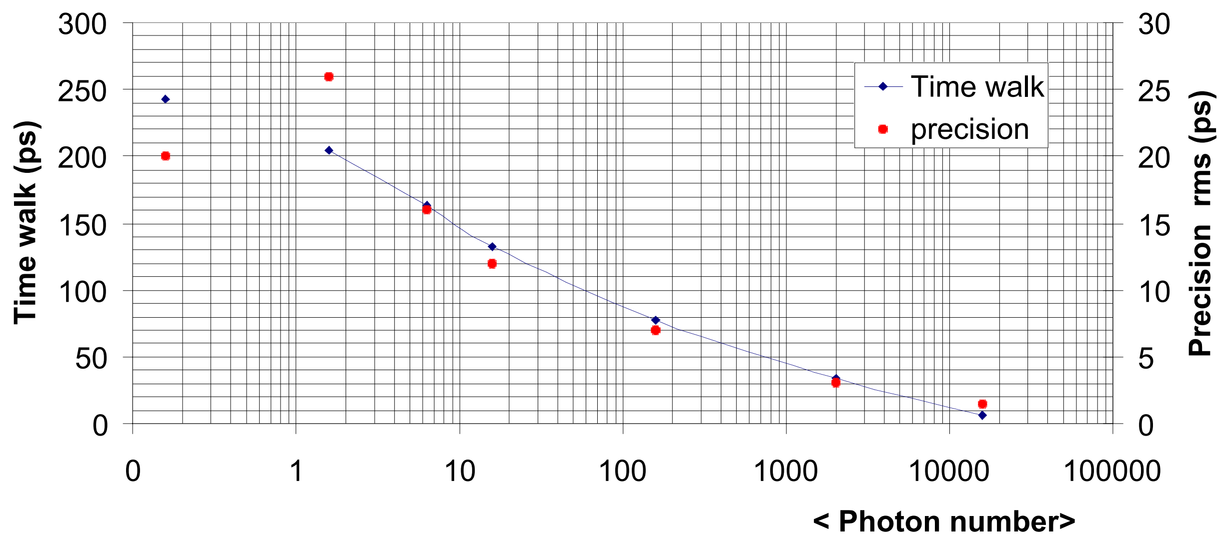

Figure 13 : Time-walk and precision in a multi photons mode.

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