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FILLING PATTERN MEASUREMENTS AT ALBA USING TIME CORRELATED SINGLE PHOTON COUNTING

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Time Correlated Single Photon Counting. The technique consists in the measurements of the temporal distribution of the produced synchrotron radiation using Electro-Optical devices, from where the filling pattern is inferred. Two different photomultipliers are used to perform the measurement and results are compared. A further comparison between results from the photomultipliers and the FCT is performed to verify the accuracy of the results.

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Abstract

At the ALBA synchrotron light source, the filling pattern is measured using a Fast Current Transformer (FCT). Applying a data analysis the filling pattern is measured with a dynamic range in the order of 10^2, limited by the electronic noise in the device. A new experimental set-up for filling pattern measurements was implemented using the Time Correlated Single Photon Counting. The technique consists in the measurements of the temporal distribution of the produced synchrotron radiation using Electro-Optical devices, from where the filling pattern is inferred. Two different photomultipliers are used to perform the measurement and results are compared. A further comparison between results from the photomultipliers and the FCT is performed to verify the accuracy of the results.

INTRODUCTION

ALBA synchrotron light source [1] is operative since 2012 and by the end of June the machine will run in top-up mode. The top-up will guarantee a constant current and, as a consequence, a constant flux of synchrotron radiation, by frequent subsequent injections. To obtain a flat filling pattern the injections should be selective in order to start the refilling from the emptiest bunches.

Since its commissioning in 2011, the filling pattern is measured using a Fast Current Transformer (FCT) and treating the acquired data with a dedicated analysis. The device allows to obtain dynamic range of 10^2 limited by the electronic noise [2].

To improve the measurement and to have redundancy, we decided to use the Time Correlated Single Photon Counting technique (TCSPC) [3] based on the detection of the temporal distribution of the synchrotron radiation. Measurements were performed in ALBA diagnostic beamline Xanadu using the visible part of the radiation since its temporal distribution is the same as the one of the electrons that generate it.

The temporal distribution was obtained measuring the arrival time of several photons at a fixed position in the beamline where a photon-detector was located. The time distance was measured with respect to the machine clock. To avoid the pileup and to guarantee the linearity of the measurement the photon flux has to be lower than one per beam revolution. The pileup is related with the electronic dead time and provokes a higher probability of detecting photons from the first bunches. This lead to an error in the counts of the photons for bunches which follow an empty gap. Figure 1 shows a sketch of the experimental set-up.

Tests were performed using as photon-detector two different photomultipliers (PMTs) by Hamamatsu: the PMT H10721-210 and the PMT R4124.

As photon-counter we used a time to digital converter: the PicoHarp300. The device takes as input the machine clock as start and the PMT signal as stop and compute the temporal distance between the arrival time of the two signals. Start and stop are detected when the signals crosses a certain voltage threshold. The obtained temporal distances are then distributed in an histogram of 56000 channels. The minimal resolution of the device, given by the size of the binning of the histogram, is 4 ps. In our case, to measure the filling status of all the 448 buckets of 2 ns of the ALBA beam, we used a binning size of 16 ps.

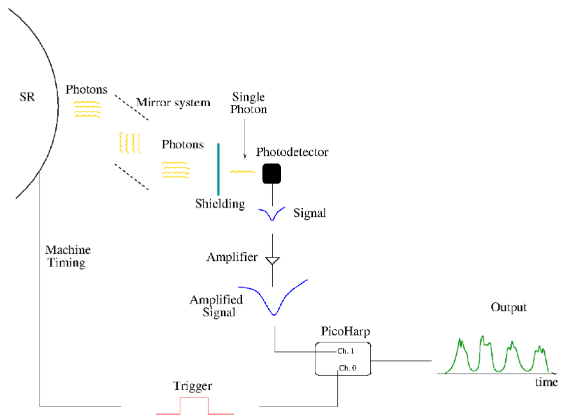

Figure 1: Sketch of the TCSPC set-up.

PMTS CHARACTERISTICS

The performance of the TCSPC technique strongly depends on the characteristics of the photon-detector used, since the stop of the temporal measurement is given directly from the output signal of the device. The main parameters of the PMTs chosen are presented in Table 1.

Table 1: Manufacturer specification of the PMTs. The Transit Time Spread that was measured in house.

	H10721-210	R4124
Photocathode Material	Ultra Bialkali	Bialkali
Spectral Response	230-700 nm	300-650 nm
Dark Current	10 nA	1-15 nA
Rise Time	0.57 ns	1.1 ns
Transit Time Spread	0.2281 ns	2.188 ns

The PMT H10721-210 by Hamamatsu is a stand alone module that require 5 V input voltage and directly provides a voltage output with short rise time that is necessary for the success of the TCSPC technique. The R4124 is a raw device that needs 1 kV as input voltage. All the electronic was developed in-house. The output is a current signal, for this reason a current amplifier (HCA-40M-100K-C by FEMTO) is needed to convert the output into a voltage signal. The rise time of the pulse is not as short as for the other device but is still shorter than the bucket length, enough for the TCSPC.

Another important characteristic of the photon-counter is the Transit Time Spread (TTS) that was not unfortunately provided by the manufacturer. The TTS is defined as the FWHM of electron transit time fluctuation between the arrival time of the photon to the photocatode and the signal generation, and can be identified as the time jitter of the output pulse.

To perform the measurement of the TTS, photons from a point-like source have to be detected. A single electron bunch can be considered a point source since the TTS of the PMTs (few hundreds of ps) is larger compared with respect to the ALBA bunch length (16 ps). For this reason we used synchrotron radiation produced with the machine operating in single bunch mode to measure the TTS. The visible light was guided up to the beamline and attenuated down to one detectable photon per beam revolution and the time distribution of the arriving photons was measured using the Picoharp300. This provided a direct measurement of the TTS. The results of the measurements are shown in Fig. 2 and are presented in Table 1.

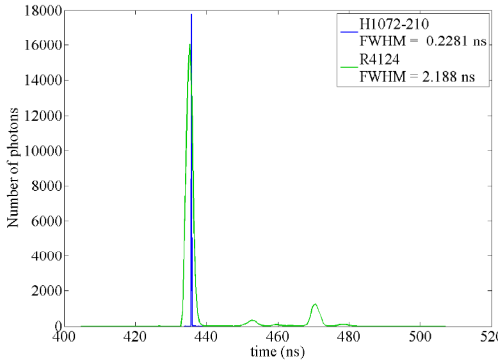

Figure 2: Measurements of the TTS of the two PMTs. In blue the TTS of the H10721-210 that is much shorter with respect to the one measured for the R4124, in green.

The TTS of both PMTs was not found to be as good as the one of the best devices used to perform TCSPC measurements in other machines [3,4], but, in the case of the PMT H10721-210 was short enough to fit in the bucket length (2 ns). This was not valid of the R4124 for which the TTS was found to be longer compared to the bucket temporal length and for this reason photons coming from one bunch might be counted in one of the two adjacent. This behavior could negatively affect the measurements since might provoke the mixing of consecutive buckets.

Another interesting aspect of this measurements was the presence of some smaller peaks following the main one generating a sort of ringing in the signal. Since they are systematic and easily recognizable, they were not considered in the computing of the dynamic range.

TCSPC MEASUREMENTS

Using both the photomultipliers we measured the filling pattern with the TCSPC. The general set-up was explained in the previous section.

To lower the photons rate down to maximum one per beam revolution, to avoid the pileup, we used neutral density and color filters. This last choice was also related with the spectral response of the PMTs since this parameter varies with the energy of the photons. The optical components were mounted in a black tube and placed in contact with the device to reduce the background coming from external light, as shown in Fig. 3.

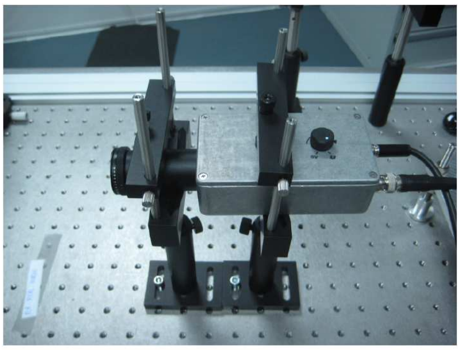

Figure 3: Final set-up of the PMT H10721-210. The device is inside the metallic box, which also contains the electronic connections. The optical components to lower the photon rate are located in the black tube.

To optimize the data acquisition system, we performed scans in the photon counter threshold, Figure 4 contains the obtained dynamic ranges for both the PMTs.

According to this scan the thresholds and the time of data acquisition were set to:

- PMT H10721-210, Thr. = 20 mV, ac. time = 5 s;
- PMT R4124, Thr. = 10 mV, ac. time = 60 s.

For the PMT H10721-210 we did not chose the threshold at 15 mV because it presented some pileup in the first bunches.

Thanks to its short TTS the PMT H10721-210 allowed to distinguish the different bunches wile the R4124 did not.

The results were post-processed summing all the photons counted within a bucket, normalizing the distribution and redistributing the total current measured with a DCCT among the bunches. In both cases filling patterns were compatible with the one obtained with the standard ALBA FCT measurements (see Fig. 5), especially for the PMT R4124. In the

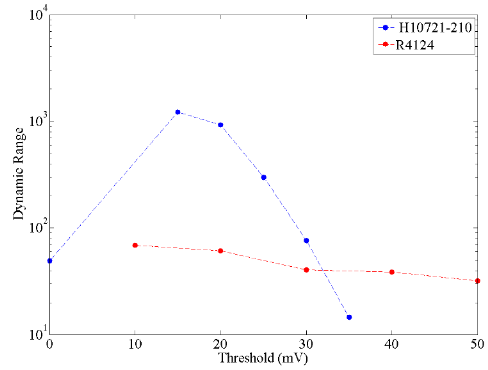

Figure 4: Dynamic range scanning the threshold. PMT H10721-210 (in blue) achieves a dynamic range higher than 10^3 while PMT keeps lower than 10^2.

case of the PMT H10721-210 a slightly larger peak ($\simeq 5\%$) was always present at the end of each train. This cannot due pileup since in our case the lack of linearity was concentrated at the filling pattern natural peaks. We related this phenomenon to the auto-gain of the device that might prejudice its temporal response. Further tests will be performed to verify this hypothesis.

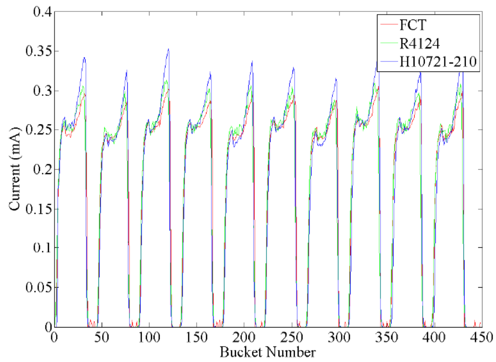

Figure 5: Comparison of the filling pattern measured with the FCT (in red), the PMT H10721-210 (in blue) and the PMT R4124 (in green). The PMT H10721-210 presents a higher peak with respect to the other two devices, around 5%.

On the other side the result from the PMT H10721-210 had very low background that allowed to measure very small bunches. ALBA filling pattern is composted by ten trains of 32 bunches each. Using the TCSPC with the PMT H10721-210 we were able to notice that a 33-rd satellite bunch was always present at the end of each train. For normal bunches we counted during the data acquisition around 15000 photons, while for the satellite bunch we counted around 150 and it was clearly defined. The background level was set around 5 photons so we obtained a dynamic range higher than 10^3. An image of a single train and the satellite bunch is presented in Fig. 6. We were not able to distinguish the satellite bunches with the PMT R4124 since the dynamic range was around 10^2.

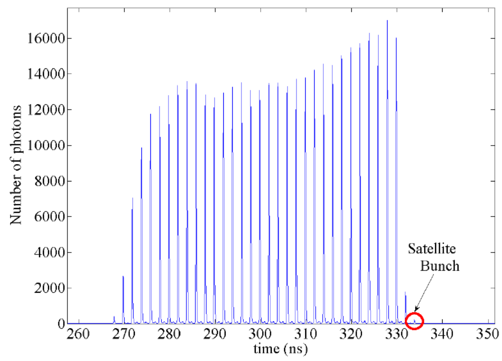

Figure 6: Single train measured with the TCSPC using the PMT H10721-210. A satellite bunch is present at the end of the train.

CONCLUSION

We tested two different photomultipliers to be used as photon-detector for the TCSPC technique. The PMT H10721-210 presents a good response time but the auto-gain system causes some mismatching in the filling pattern reconstruction. The estimated dynamic range of the measurements with this device was higher than 10^3. The PMT R4124 provided a reliable filling pattern but the dynamic range was estimated to be around 10^2. In terms of costs versus performance both the PTMs prvide an effective choice.

A further step will be to implement the set-up inside the tunnel and integrate the measurement within the top-up injection system.

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