

TIME CORRELATED SINGLE PHOTON COUNTING USING DIFFERENT PHOTON DETECTORS

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Abstract

Time Correlated Single Photon Counting (TCSPC) is used in accelerators to measure the filling pattern and perform bunch purity measurements. The most used photon detectors are photomultipliers (PMTs), generally used to detect visible light; and Avalanche Photo-Diodes (APDs), which are often used to detect X-rays. At ALBA synchrotron light source, the TCSPC using a standard PMT has been developed and is currently in operation. Further tests have been performed using an APD. This work presents the experimental results using both detectors, and compares their performances.

INTRODUCTION

The Time Correlated Single Photon Counting (TCSPC) is largely used in several accelerators to perform Filling Pattern (FP), and Bunch Purity measurements [1, 2]. The technique allows real time, and non-destructive FP measurements using the synchrotron radiation and providing high dynamic ranges.

The TCSPC is based on the fact that the number of photons produced when the beam is passing through a bending magnet is directly proportional to the number of electrons in the beam. Therefore, the FP can be obtained by measuring the temporal distribution of the synchrotron radiation, which corresponds to the one of the electron beam.

At ALBA the TCSPC using visible light has been successfully tested (see [3] for details), and more recently, a final setup for the routine operation has been developed. Moreover an Avalanche Photo-Diode (APD) has been also tested to perform TCSPC using x-rays.

The final setup for the visible light, and the new setup for the x-rays are presented in this work, together with a discussion on the obtained results.

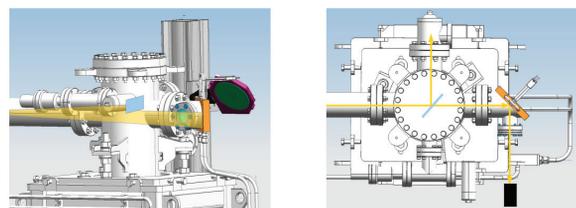
Table 1: Manufacturer specification of the PMT and the APD. The Transit Time Spread that is measured in house.

	PMT H10721-210	APD C5658
Photocathode Material	Ultra Bialkali	Silicon
Spectral Response	230-700 nm	200-1100 nm
Dark Current	10 nA	0.1 nA
Rise Time	0.57 ns	0.5 ns
Transit Time Spread	0.2281 ns	0.47 ns

TCSPC USING VISIBLE LIGHT

The photon-detector used to perform TCSPC in the visible range at ALBA is a Hamamatsu photomultiplier (PMT) H10721-210. The main characteristics of the device are collected in Table 1, and preliminary tests are shown in [3].

The final TCSPC setup has been moved for operation stability reasons inside the tunnel. The light is extracted using the copper absorber located at the end of visible light diagnostic frontend. This is possible since the synchrotron light reaching the ALBA diagnostic beamline Xanadu is extracted through an “half-mirror” which selects only the upper lobe of the radiation generated. In this way the central and the lower lobe reach the copper absorber, which is oriented at 45° with respect to the incident light. Even if the absorber is not polished, it is still able to reflect the visible light which is extracted through an extraction window, after which the PMT is located. A sketch of the light path at the end point of FE01 is presented in Fig. 1.



(a) Front view.

(b) Top view, the black box represents the PMT.

Figure 1: Layout of FE01 endpoint and sketch of the light path.

In order to avoid the contaminations from the visible ambient light in the tunnel, a container has been designed to accommodate the TCSPC final setup. The container is a black box fixed on a support, and is directly connected to the secondary extraction window of FE01.

The PMT is contained in a small box in order to make the cabling easier (see Fig. 2(a)). On the front part of the box a c-mount lens tube is mounted, holding a Neutral-Density (ND) filter and a 633 nm band pass filter in order to shield the radiation and low the flux to less than one photon per revolution period, as required from the TCSPC. In front of the PMT box, a motor allows to introduce a gradual ND filter (from 0 to 10⁵) to control the photon flux.

Lead sheets have been located around the PMT to reduce the noise produced by particle losses and to slow down the device aging process.

Figure 2 shows two pictures of the setup. In the first the container is open and all the components are visible, while in the second the box is closed and is mounted in the tunnel at the FE01 location.

The power supply and the required electronics to properly control the components in the container (PMT and motor) are located outside the tunnel. The PMT signal is connected to a PicoHarp300, which acquires the data and send them to

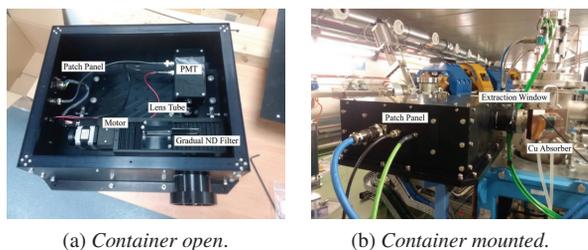


Figure 2: Final setup for TCSPC using visible light.

the ALBA control system where an on-line data analysis is performed [3]. A Tango version of the PicoHarp300 software has been developed in house [4].

Filling Pattern Measurements

TCSPC using visible synchrotron radiation is nowadays used routinely at ALBA for FP monitoring during machine operation, where 130 mA of current are distributed in the 10-trains with 32 bunches each. The integration time used to perform TCSPC is 10 s, with a bin width for the PicoHarp300 of 16 ps.

The typical raw data are presented in Fig. 3. In the top plot all the ten trains of the ALBA FP are presented: the horizontal scale is a machine period. The bottom plot is the zoom of the first train of the the FP. The peaks have a modulation of 2 ns, which corresponds to the 32 train bunches. The number of photon counted each 2 ns is proportional to the amount of current per bunch.

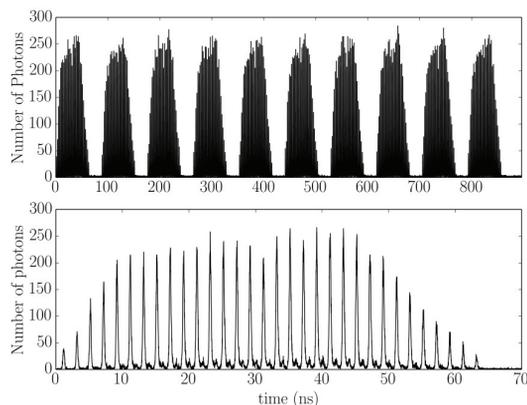


Figure 3: Results from TCSPC using visible light. The top plot is the whole beam while the bottom plot is a zoom on the first train.

Single Bunch Measurements

Single bunch measurements were also performed using this configuration. A single bunch of 5 mA was injected at the bucket 3 (around 6 ns), and some spurious counts appeared at bucket 12 (around 24 ns), as presented by the black line of black line in Fig. 4. Not being sure of the nature of the spurious counts we applied the bunch cleaning. The result is

given by the red line in the same Figure, where the spurious counts disappears. The bunch cleaning has also been applied to the surrounding buckets but no improvements were observed.

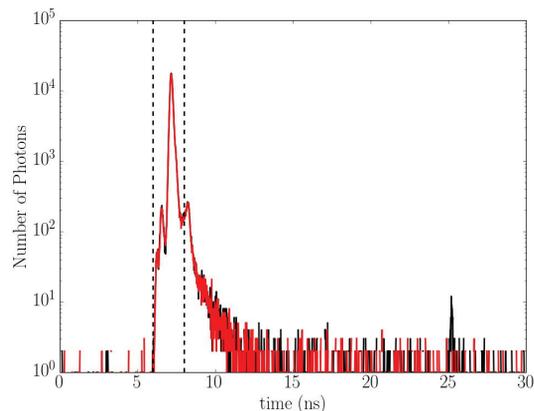


Figure 4: TCSPC to measure a single bunch of 5 mA using the PMT. Data were acquired for 15 s. Horizontal dashed lines represent the bucket length.

More in general, the response of the PMT presents a sharp peak, with a maximum of roughly 10^4 counts per bin, centered within one bucket (from 6-8 ns, dashed vertical lines in Fig. 4). The PMT signal decays of two order of magnitudes in the 2 ns delimiting the bucket length, which define a dynamic range of 10^2 . On the other side the PMT has been able to detect in a separate bucket very small amount of current that only produced around 10 counts. This provide a dynamic range of 10^3 .

It is worth to notice that during standard operation FP measurements, since we are not interested in the bunch purity, the maximum number of photon counted per bin is in the order of a few hundred (see Fig. 3). In this count range the profile of the single bunch stays within one bucket and photons coming from different bunches are not mixed, minimizing the effect on the linearity of the measurement.

TCSPC USING X-RAYS

The device chosen to perform TCSPC at ALBA is the APD module C5658 by Hamamatsu [5]. The silicon detector included in the module is the Hamamatsu Si APD S12023-02 [6], the effective area has a diameter of 0.2 mm. The full integrated module also contains a bias power supply and a low noise amplifier. The gain of the module is set to 50 (for light in the visible range), and the detection limit is up to 1 GHz. In order to guarantee a stable operation of the APD, a thermosensor and a temperature-compensated bias power supply are also present in the integrated module.

This kind of detector is thought to detect visible light in a range from 200 to 1100 nm, but since the APD will be used for x-ray detection, the foreseen borosilicate window has been removed. The main specifications of the module and the silicon detector are listed in Table 1. Note that

all the parameters (but the Transit Time Spread which is measured in house) refers to the behavior of the detector when measuring visible light pulses.

Following experiments at other machines [1,7,8], the goal is to use the secondary x-rays produced from the collision between the synchrotron radiation beam and a metal, such as copper, to measure the FP. When copper is bombarded with hard x-rays some electrons transitions to the innermost K shell from a $2p$ orbital of the second, or L shell are exited, and soft x-rays (about 8 keV) are emitted. Figure 5 (top) shows the position of the peaks for this kind of transition in copper. The so called K_{α} and K_{β} transitions are very fast (order of 10 ps) so they can be used to detect indirectly the arrival time of the photons [9]. Moreover the fluorescence yield is around 50% for copper, as shown in the rightmost plot in Fig. 5 (bottom). This means that roughly half of the x-rays that are absorbed will produce the transition and generate softer x-rays, while the others will generate Augers electrons.

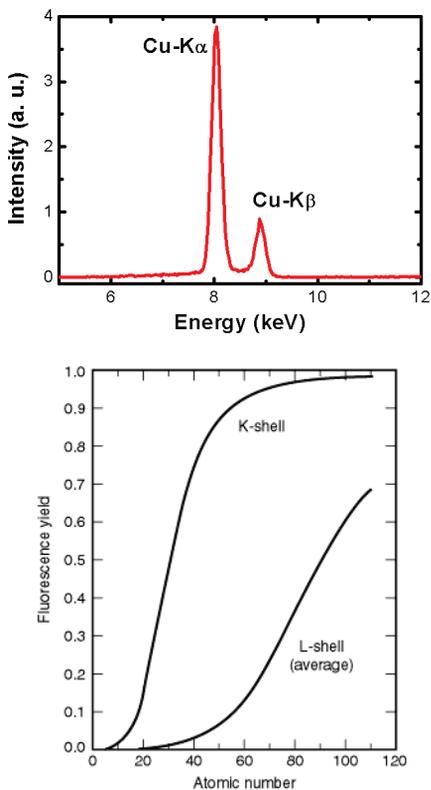


Figure 5: Intensity of the K_{α} and K_{β} transition of copper and fluorescence yield for metals [9]. The copper atomic number is 29.

To exploit the K_{α} transition, the APD has been located looking at the copper filter used for the x-rays pinhole at Front-End 34 (FE34), as presented in Fig. 6. A bending magnet generates the synchrotron radiation, X-rays are extracted through a 1 mm aluminum window selecting photons with an energy larger than 1 keV. A copper filter, with a thickness

of 0.5 mm, selects x-rays with an energy larger than 12 keV to perform pinhole imaging avoiding diffraction limitation.

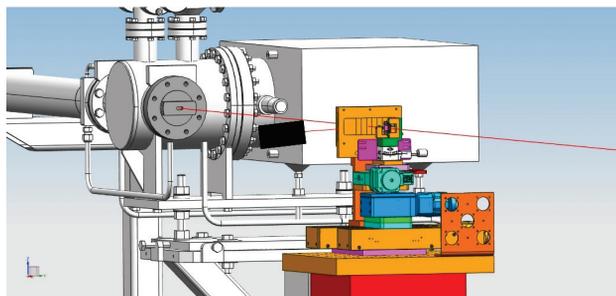


Figure 6: FE34: the x-rays (red line) are extracted through the aluminum window and filtered by a copper absorber (orange parallelepiped). Red line outgoing from the filter represent part of the K_{α} transition reaching the APD (black rectangle).

The filter can be used as source of K_{α} . Note that only x-rays absorbed in the first 20 μm of Cu provide suitable K_{α} photons, being 20 μm the attenuation length for photons of this energy in the material.

The APD C5658 provides a positive pulse with an amplitude that depends on the energy of the x-ray detected. To make the signal compatible with the PicoHarp300, which only accepts negative pulses, a delay generator DG645 [10] has been used to invert the signal. The pulse from the APD is given as input trigger to the DG645, which finally produces a squared pulse of negative amplitude (-600 mV) and short enough rise time (< 1 ns). The threshold used to fire the trigger has been set to 40 mV. This pulse is then connected to the Channel 1 of PicoHarp300 to measure the photons temporal distribution, using the same setting as for the PMT.

Filling Pattern Measurements

Measurements of the same FP shown in Fig. 3 has been performed using the APD to detect x-rays. The result is presented in Fig. 7.

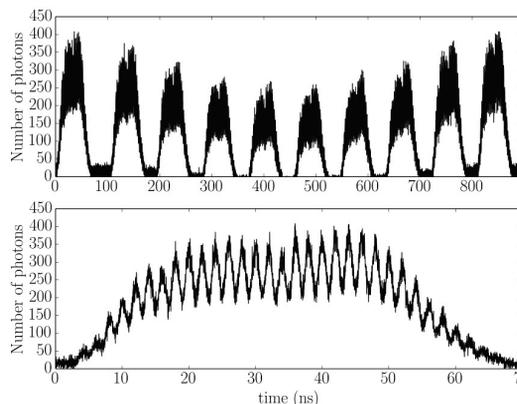


Figure 7: Results form TCSPC using the APD to detect x-rays. The top plot is the whole beam while the bottom plot is a zoom on the first train.

The APD measurements looks noisier and that the shape of the FP measured is not the same. When measuring with the APD the central trains looks less filled with respect to the “lateral” ones. This may be due to the response of the device when detecting x-rays at high repetition rate. The effect is currently under investigation because not fully understood.

Moreover the Temporal Time Spread of the device is not as good as the one of the PMT, and consecutive bunches are mixed up. This also contribute to the distortion of the measured FP. This effect is corrected in other machines using a dedicated algorithm [2].

Single Bunch Measurements

Single bunch measurements using the APD has been also performed. Data were acquired for 200 s and a bunch of 3.5 mA was placed at bucket 3 (6 ns). Results are presented by the black line of Fig. 8. Also in this case the vertical dashed lines delimit the bucket length.

To have an estimation of the sensitivity of the detector, we filled with a few shots the bucket 4 (red line of Fig. 8): it is clear that the APD is measuring the small amount of current in the bucket as an excess of counts with respect to the single bunch curve. Other shots were injected in buckets 0, 1, 2, 4, 5, and 6 changing the linac gun-level to inject less and less current [11]. Results shows that the APD was able to resolve a very low amount of particles.

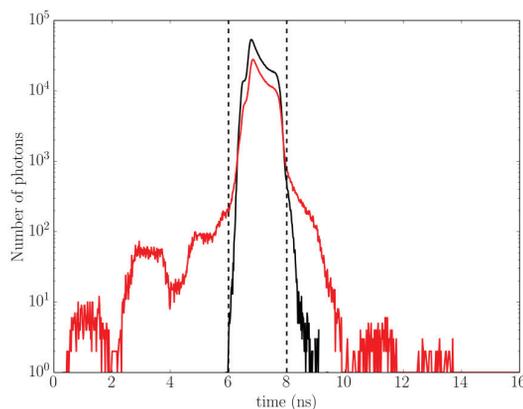


Figure 8: TCSPC to measure a single bunch of 5 mA. Horizontal dashed lines represent the bucket length.

In the APD case the signal decays of almost 3 order of magnitude in the bucket length leading to an estimated dynamic range of 10^3 . On the other hand no noise is surrounding the main bunch. Moreover the it has been proved that a modification of the signal shape can be appreciated when injecting few current in the bucket following the main one. Finally the device is also sensitive to very low amounts of current injected in further buckets, providing a dynamic range in this conditions better than 10^4 .

CONCLUSION

In this report we presented the setup and the results obtained for the TCSPC using visible light and x-rays at ALBA synchrotron light source.

From the measurements it is clear that a standard PMT using visible light is preferable to perform routine operation FP measurements since the shape of the pulse is reasonably contained within the 2 ns of a single bucket. This is not the case of the APD, for this reason, when performing multi-bunch measurements the consecutive buckets are mixed. Moreover a strange behavior of the trains trend makes the results nor fully reliable. The effect is still under investigations.

On the other side, the APD detecting x-rays seems much more sensitive when measuring single bunch showing an high dynamic range, better than the PMT.

As a consequence to this measurements the PMT has been chosen to measure the FP during routine operations, while the APD will be further investigated for bunch purity applications.

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