ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPJE071

NEW ELECTRON CLOUD DETECTORS FOR THE CERN PROTON SYNCHROTRON

C. Yin Vallgren, P. Chiggiato, S. Gilardoni, H. Neupert, M. Taborelli#, CERN, Geneva, Switzerland

Abstract

Electron cloud (EC) has already been observed during normal operation of the PS using classical shielded button pick-up detectors in drift sections. In the context of the LHC Injector Upgrade (LIU project), similar measurements are also needed for the combined function magnets of the machine, where the access to the vacuum chamber is strongly limited by the presence of the yoke. Two new electron cloud detectors have been studied, developed, and installed during the Long Shutdown (LS1) in one of such magnets. The first is based on current measurement by using a shielded button-type pick-up with a special geometry to reach the bottom surface of the vacuum pipe embedded in the magnet. The second one relies on a newly developed measurement method based on detection of the photons, which are emitted by cathodoluminescence from the electron cloud impinging on the vacuum chamber walls. Part of the emitted photons is collected through a quartz window by a Micro-Channel Plate Photomultiplier Tube (MCP-PMT). First results obtained during machine development runs show the feasibility of the photon detection scheme. The results are discussed and compared with pick-up measurements.

INTRODUCTION

The direct measurement of the electron cloud (e-cloud) current in an accelerator implies to collect part of the electrons arriving to the beam-pipe. The collected electrons no longer contribute to the e-cloud development and therefore the measurement slightly perturbs the electron multipacting. Such measurements are more difficult in a magnetic field, since the dedicated vacuum beam pipe must have sufficient space to host the collector electrode without aperture restrictions for the machine [1]. In order to follow the e-cloud effect in the Proton Synchrotron (PS) accelerator at CERN in the context of the LHC Injector Upgrade program, we explored the development of a device which can monitor the signal of the electrons without collecting them directly. Such a device was implemented in one of the standard combined function magnets of the PS accelerator.

PRINCIPLE OF OPERATION

The principle of operation is the detection of cathodoluminescence [2, 3] photons produced by electrons impinging on a metallic surface. The decay of the secondary electrons to lower energy states, after the excitation by the primary electrons in the solid, occurs partly by photon emission. Figure 1 illustrates the spectrum of the photons obtained with an electron beam of 300eV, 9μA (area 2 mm^2) impinging on a stainless steel 316LN as-received surface (same material as the wall of the PS vacuum pipes). The beam energy is representative of the electrons of the e-cloud impinging on the accelerator wall. The light emitted by the sample is collected by a spectrometer (Andor Shamrock 303i, CCD Andor iDus 420) in air from a quartz viewport attached to a dedicated UHV chamber hosting the sample and the electron gun. The cold BaO cathode (nominal operating T=1150 K) of the gun aims at minimizing the black body radiation in the near UV region, where the

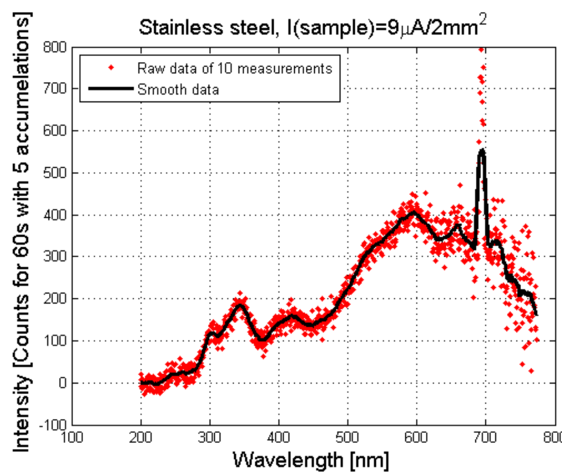

Figure 1: Typical spectrum obtained with e-gun.

cathodoluminescence is expected [2,3]. Most of the cathode radiation is indeed above 700 nm. This is proved by the fact that the signal in the range shown in figure 1 vanishes when the electron beam is deviated away from the sample. As expected the intensity is found to be proportional to the primary current impinging on the sample. A Monte Carlo simulation shows that the efficiency of collection due to the solid angle of the setup is only 0.04% (assuming isotropic emission). From this value and the measured integrated intensity between 200nm and 700nm we obtain a yield of 5×10^{-11} ph/e which is compatible with the literature values [2, 3].

SETUP FOR THE PS AND TESTS IN THE LABORATORY

The setup installed in the PS is shown in the scheme in Fig. 2. After the quartz viewport of the vacuum chamber the light is collected by a UV compatible optical system and brought to a PMT. The PMT (Photonis PP0365G) is robust with respect to parallel magnetic fields up to 2T and is placed in order to be parallel to the fringe field of the magnet. It has a nominal efficiency of 30% at 200-400 nm decreasing from 20% to 3% in the range 400 to 700

#mauro.taborelli@cern.ch

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPJE071

nm. Most of the electronics sits outside of the PS tunnel for radiation reasons in contrast to the spectrometer described in the previous section, the setup for the accelerator collects the full spectrum of wavelength which can be transmitted by the optics and detected by the PMT. The dark current and sensitivity of the optical setup and PMT were first tested in the lab by closing the entrance of the device. The signal of the "blind" detector is shown in Fig. 3 (right panel). Approximately we observe an average of one peak per microsecond having an amplitude ≥ 20mV, which is more than twice the noise level.

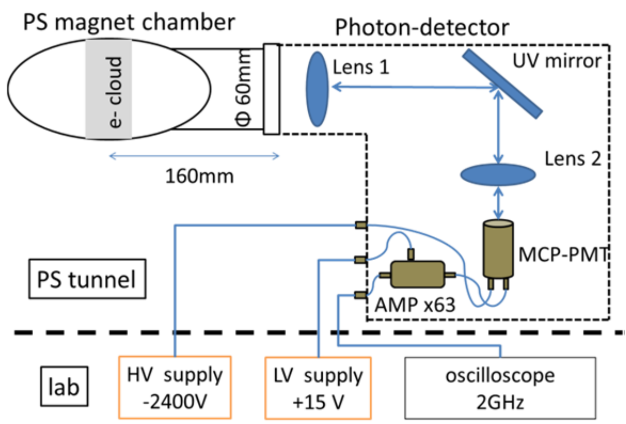

Figure 2: Schematic setup of the detector in the PS.

By switching on the ambient light in the lab the number of peaks per microsecond with the amplitude above 15 mV increases by about one order of magnitude. The box containing the optics and the photomultiplier is not perfectly tight to light (this was only for the laboratory test and has been improved) and this explains the increase of the counting rate. The sensitivity of the device is correct, since the well separated single peaks having all about the same amplitude can be ascribed to single photons.

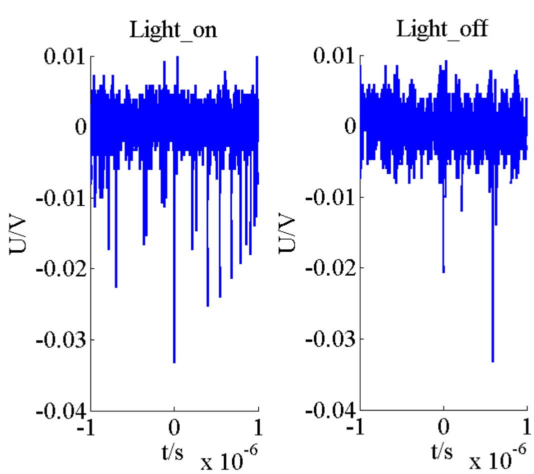

Figure 3: Signals detected in the lab, with ambient light off (right) and on (left).

SYSTEM IN THE PS

From simulations [4] of the e-cloud process the light is expected to be emitted from a 40 mm stripe at the top and bottom walls of the magnet vacuum chamber, where the electrons impinge. The transmission efficiency of the photons to the PMT has been simulated by Monte Carlo calculation by assuming isotropic photon emission on 40 mm wide and 100 mm long stripes at the top and bottom of the magnet chamber in front of the viewport. A diffuse reflectivity of the entire stainless steel surface of 40% was assumed. Only 1% of the photons are transmitted to the PMT. The transmission can be improved to 8% by adding a high reflectivity (85% according to [5]) sheet of MgF_2/Al coated polyethylene in the vacuum flange tube. This solution was also implemented in the PS. By assuming an e-cloud density of 1 μA/mm^2, as from [4], in the relevant area of the chamber, the efficiency of photons per electron mentioned above leads to a photon current of 10^5 photons/s during e-cloud. The dark current in Fig. 3 (right) is one order of magnitude lower.

The dark current and the noise measured after installation in the PS without beam in the machine are comparable to the measurements in the laboratory. In order to verify any possible perturbation from the circulating beam the detector has been first mounted as in Fig. 2, but with a dark foam disk between its aperture and the chamber viewport, so that no visible or UV photon could reach the PMT. The result for an acquisition at 250 Ms/s and an LHC type proton beam with 9.6 x 10^{12} protons in 72 bunches at 25 ns bunch spacing (or 1.3 x 10^{11} protons/bunch) is shown in Fig. 4.

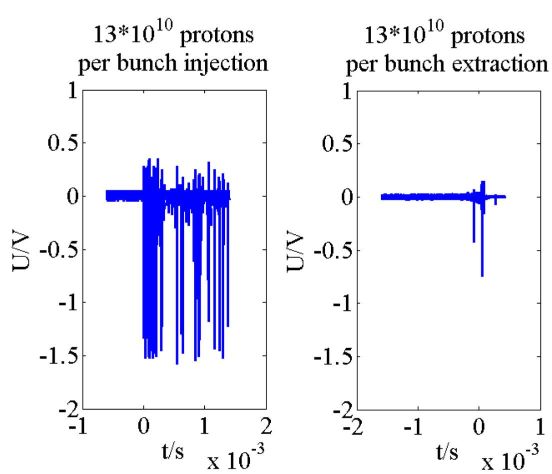

Figure 4: Signal in the photon detector with closed aperture: just after injection (left) and just before extraction (right). The zero of the abscissa correspond to the injection and extraction time, respectively.

In the right part of Fig. 4 the time 0 corresponds to the injection of the beam in the PS. The synchronization has been verified with the signal of a non-shielded pick-up installed in the same magnet. Surprisingly a very strong signal in a sequence of peaks is immediately observed with the "blind" detector and in a period of the machine

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPJE071

cycle, where the bunch length is large and simulations do not foresee any e-cloud [4]. At the end of the cycle, just before extraction and after acceleration (Fig. 4, right) a weaker signal is also observed. The peak amplitude is up to 100 times larger than for the single photon events in Fig. 3. By increasing the sampling rate of the oscilloscope to 2 Gigasamples/s the large parks appear as a single spike with damped oscillations during about 20 ns length, which can be considered as the time resolution of the system. The overshoot on the positive voltage side is also understood from the damped oscillations, which are a consequence of the imperfect coupling of the transmission line (about 50 m of cables). In order to justify such a high signal amplitude one should assume the emission of hundredth of photons. In fact the detected signal is ascribed to proton losses resulting in a shower of secondary particles, which reach the PMT or the electronics by crossing the steel vacuum chamber and the housing of the device. We believe that the striking difference between the signal observed at injection and extraction is related to the difference in beam size and hence proton losses. The accelerated beam before extraction has lower emittance and the losses are almost negligible, whereas at injection the losses of the larger emittance beam are more pronounced. In order to reduce the effect of proton losses and related secondary particles we plan to add a suitable radiation shielding on the electronics of the device and to move it further away from the magnet if this is not sufficient. Figure 5 is a magnification of part of Fig. 4 (right side) displaying the difference in the noise level with and without beam. Apart of the large peaks the signal before time zero shows a continuous band of noise of 20 mV peak-to-peak, which is similar to the amplitude of single photons signals in the laboratory tests (Fig. 3). Keeping in mind that this is measured with the closed detector, such a noise would hinder to distinguish single photon signals. After the beam extraction the noise decreases to the value measured in the laboratory.

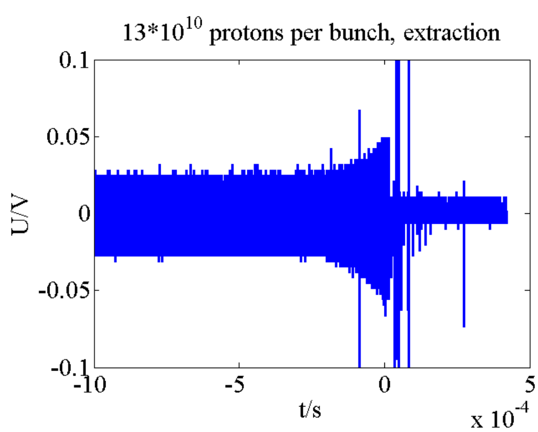

Figure 5: Magnification of the signal shown in Fig. 4 close to beam extraction.

The origin of this noise is presently under investigation. In this magnified view it is easy to verify that some of the huge peaks occur also after extraction (after time 0). It is very likely that a spurious residue of the beam remains in the machine after extraction and causes losses. We plan to verify this hypothesis by monitoring the signal modification when adding a further kick with few ns delay in order to extract also this residual beam. This would definitely prove the relation between the proton losses and the large peaks. The behaviour of the photon detector in presence of the beam has been verified also with the open aperture. Close to extraction the signal consists mainly of large spikes similar to those in Fig. 4 and 5.

CONCLUSIONS

A new principle for the detection of e-cloud electrons has been explored. The method is based on the detection of cathodoluminescence. Laboratory measurements have shown that the efficiency of photons production by the impinging electrons is in principle sufficient to give the necessary sensitivity. In the first implementation of the device in the PS accelerator shows that the signals are masked by a strong background probably produced by proton losses and related shower of secondary particles. Further developments are planned in order to access the e-cloud generated signal.

CONCLUSIONS

We thank G. Rumolo and G. Iadarola for helpful discussions and the PS operators for the setup of the machine during the tests. The help of M. Palm during the construction and test of the detector is warmly acknowledged.

REFERENCES

[1] C. Yin Vallgren et al Phys. Rev. ST, Acc. and Beams 14, 071001 (2011).
[2] B. Papanicolaou and et. al., J. Phys. Chem. Solids, vol. 37, pp. 403-409, 1976.
[3] P. Borzyak et al.,Zh. Eksp. Teor, Fiz, vol. 80, pp. 1514-1523, 1981.Borzyak.
[4] LIU Technical Design Report, Volume I, CERN-ACC-2014-0337 - 15 December 2014, CERN Geneva, p.316.
[5] http://ph-news.web.cern.ch/content/na62-mylar-reflection-coating-almgf2