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Abstract:

This report describes the first steps towards the build-up of an experimental set-up in BL34 to measure the transverse electron beam size using visible light. The goal is to obtain reliable bunch-by-bunch beam size measurement using a Fast Gated Camera, property of the BI-Group at CERN. This is held inside the CELLS-CERN collaboration for the CLIC project.

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Proposal for a bunch by bunch beam size measurement using Visible Light at ALBA

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Summary

This report describes the first steps towards the build-up of an experimental set-up in BL34 to measure the transverse electron beam size using visible light. The goal is to obtain reliable bunch-by-bunch beam size measurement using a Fast Gated Camera, property of the BI-Group at CERN. This is held inside the CELLS-CERN collaboration for the CLIC project.

1 Introduction

ALBA is currently operating in "decay" mode, by which we inject up to 120 mA (exact value depending on the users requirements) and leave the beam decay during 12h, when we re-inject again up to the initial value. Since the Storage Ring (SR) commissioning in 2011, ALBA observed an emittance blow-up when increasing the beam intensity above a certain threshold, consistent with a Coupled Bunch Instability (CBI) whose nature is unclear. The blow-up is controlled by increasing the chromaticity (see Fig. 1). We also observed that the intensity threshold increased along the time (as vacuum cleaning was taking place), and so we suspect that this instability is related with the presence of ions, particularly with a form of Fast Ion Instability.

For the time being, ALBA is lacking of any sort of bunch-by-bunch Diagnostics, and so the information obtained from the beam size or tune shift is related to the average behaviour of the full train. Transverse beam size measurements are taking now with the classical pinhole system using the x-ray part of the synchrotron radiation produced in a dipole [1]. Since the minimum exposure time of the CCD camera is 100μs, and the SR revolution time is 0.896μs, this means that the pinhole image refers to an average of about $100/0.896 = 111$ turns of the whole bunch train.

In order to properly investigate this issue, it was planned to install a set-up to measure the beam size bunch-by-bunch. One of the main challenges is to obtain an image with a gate similar to the ALBA bunch spacing (2 ns), and this can be carried out by the Fast Gated

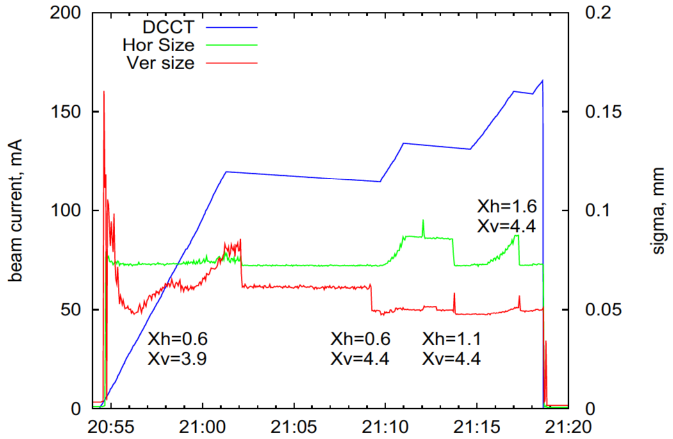

Figure 1: Evolution of the beam size while injecting up to 170mA. The emittance blow up is controlled by increasing the chromaticities.

Camera (FGC) that is loaned by CERN to CELLS.

CELLS will profit of this collaboration by introducing a new element able to obtain images in a 2 ns window, while CERN will have a hands-on experience in a machine similar to the future CLIC Damping Ring (DR). Table 1 shows the comparison between the ALBA and CLIC Damping Ring (DR) main parameters.

Table 1: Main beam parameters for ALBA and CLIC DR.

Parameter	ALBA	CLIC DR
energy, GeV	3.0	2.86
circumference, m	268.8	427.5
n. of bunches (typ)	312	360
hor norm. emit, um-rad	25.3	0.472
energy loss/turn, MeV	1.06	3.98
bunch population, e-$\times 10^9$	4.09	6.2 (max)
bunch length, mm	4.5	1.6
harm. number, h	448	2851
rf frequency, GHz	0.5	2
rf voltage, MV	3.6	4.5

2 Experimental set up

ALBA is equipped with two diagnostics Front Ends, both using the radiation produced by bending dipoles. The pinhole system uses the x-ray part of the spectrum produced by the dipole BM32 (just upstream the injection section). The second uses the visible light from the dipole BM01 (just downstream the injection section), and includes a series of 1 in-vacuum mirror plus 6 in-air mirrors that guide the visible light to the optical hutch of the BL34 - Xanadu. Figure 2 (left) shows the path followed by the light, and the horizontal and vertical image flip due to the mirrors.

One of the key parameters of this setup is the in-vacuum mirror, which is also the place where the radiation is filtered. The mirror can be moved up/down with a motor, from 3 (upper limit) to 0.85 mrad (bottom limit) above the orbit plane. Even at its lowest vertical position (0.85 mrad), the mirror does not interfere with the x-rays, and it only reflects the visible light. Because it only touches the upper part of the radiation, this mirror is often called "half-mirror". The mirror is also equipped with 3 thermocouples that control the temperature – see Fig. 2. After being reflected, the light leaves the vacuum chamber through a sapphire window, and then is directed towards the optical table in BL34 using 6 conventional round mirrors with a diameter of 2-inches.

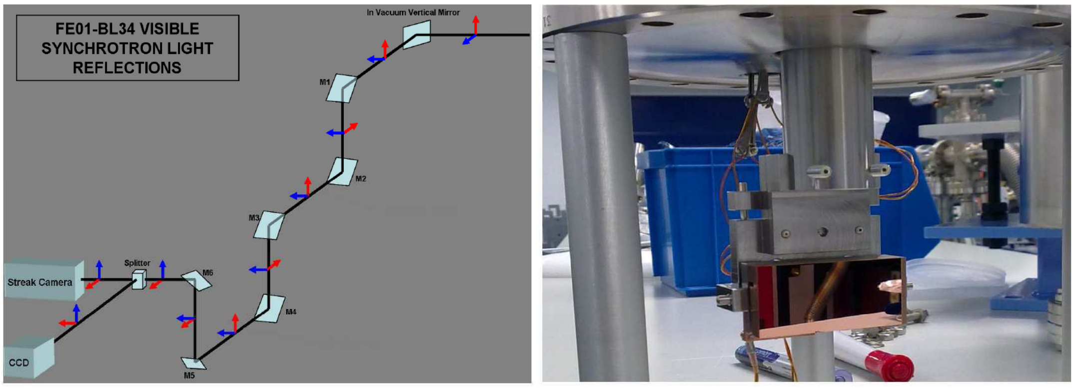

Figure 2: **Left:** Picture of the in-vacuum mirror with the thermocouples before installation. **Right:** Mirror system that guides the light to the BL34 hutch.

The horizontal and vertical apertures given by the crotch absorbers are shown in Fig. 3 (left). The limiting apertures are ± 1.84 mrad (hor) and ± 3.0 mrad (ver). Recall however that our half-mirror can only move in the vertical plane from 0.85 to 3.0 mrad. A campaign to properly align the in-air mirrors was carried out in October 2012. The image obtained at the BL34 optical hutch without any focusing element is shown in Fig. 3 (right). The origin of the light inhomogeneities is not fully understood, although it points out that possible slope aberrations and/or diffraction effects occur.

3 Fast Gated Camera Tests

The Fast Gated Camera (FGC) model is the "Redlake HG100K" from Proxitronic. It is equipeed with a fast photocathode module acting as image intensifier (GM200-3 Gate Module), which can have a gate down to 3 ns (FWHM). This should be enough to perform bunch-by-bunch images at ALBA (the bunch spacing is 2 ns).

In May 2012, a series of tests using the Fast Gated Camera (FGC) were carried out by both CELLS and CERN personnel. The timing system was developed until we control the gating down to 20 ns, and shifting this gate in steps of 8ns.

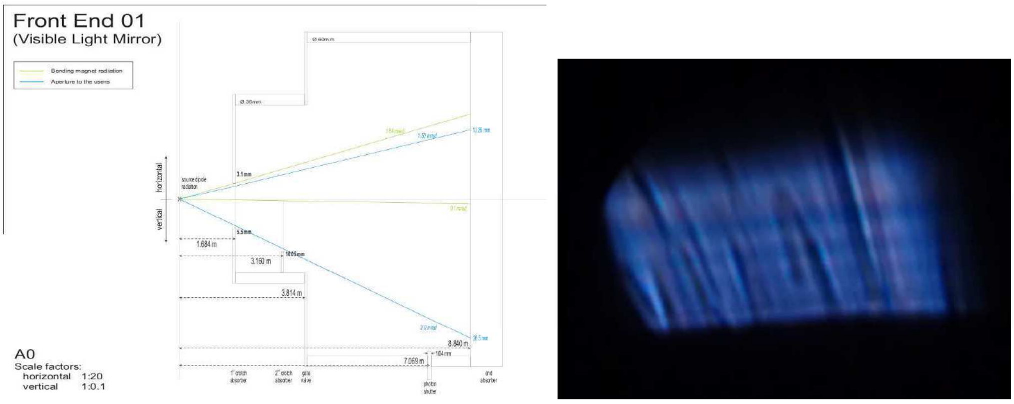

Figure 3: **Left:** Sketch with the limiting apertures in both horizontal and vertical planes at FE01. **Right:** Picture of the light arriving at Xanadu optical hutch after all the M6 mirror.

At the time of the tests, the available Function Generator is the Rhode-Schwarz AM-300, which has a certain time limitations: a) it can only provide a repetition trigger every 20-turns (instead of every turn), and b) the minimum gate is 20 ns (instead of 2 ns). With this hardware, the minimum image that could be achieved corresponds to the following settings: a) Camera exposure time: 10 ms; b) Camera repetition trigger: 20 turns and c)Intensifier Gain width: 20 ns.

With the proper synchronism, these settings correspond to an image of 10 bunches, integrated over (10 ms) / (20 turns $\times$ 0.896us)$\sim$ 558 turns. This will be improved with the use of the SRS-DG645 Pulse Generator, which has been recently acquired by CELLS. The corresponding image is shown in Fig. 4 (right), which is not properly understood. It is arguably related that the main spot corresponds to the beam image, and the "satellites" correspond to undesirable reflections. By exciting the beam with the tune excitation, the beam image does not change while the pinhole image increases from σ_y=30μm to 50μm. This is to be expected, as the image is limited by diffraction effects. In order to overcome this limitation, a new setup based on inteferometry based is foreseen [2].

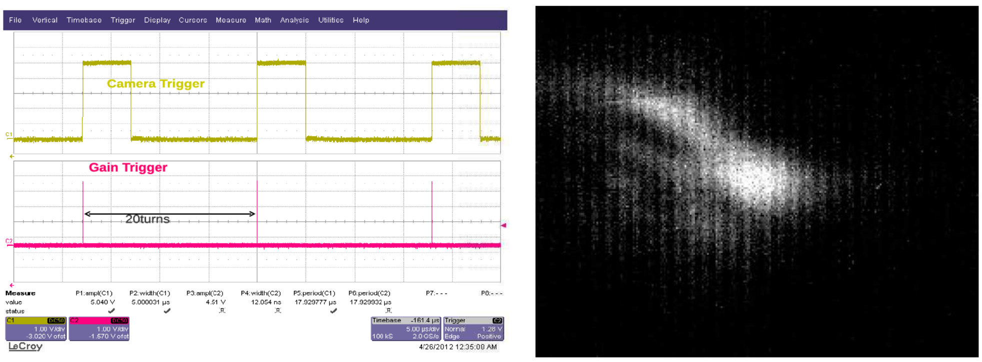

Figure 4: **Left:** Timing of FGC at scope. **Right:** Beam Image corresponding to 10 bunches. Several reflections are affecting the image.

4 Interferometer

As seen in the previous Section, the beam image using the visible light arriving at BL34 is limited by diffraction and optical effects related with the use of refractive lenses, which induce dispersion and chromatic errors. In order to overcome these limiting effects, we study the possibility to install an interferometer set-up based on the existing systems at other machines [2, 3, 4].

To make the first tests, we install a double slit system downstream the M3 mirror (see Fig. 2). This M3 mirror is already outside the tunnel, in the optical hutch. The sketch of the system is shown in Fig. 5. Just downstream the M3 mirror (at 11.542 m from the source point), we locate a double slit system with the following characteristics:

slit widht: 750 um
slit separation: 10 mm

Next, an achromat lens of f=4 m focuses the ligth at the optical table, where the image is taken by the CCD. (For the time being and in order to not risk damagin the FGC, all the interferometer tests are done with the CCD). Upstream the focal plane, we introduce a wavelength filter and light polarizer to obtain a proper interference pattern.

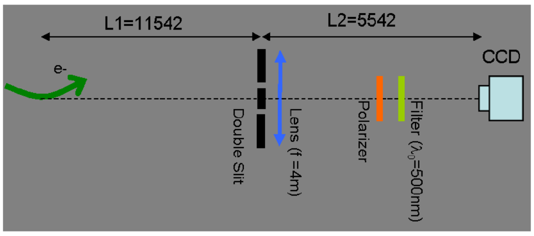

Figure 5: Configuration of the experimental set-up for the interferometertests at BL34.

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The example of an interference pattern in the horizontal plane is shown in Fig. 6. The pattern is a bit washed out due to a non-ideal choices of the experimental tools, and so is the result: while we were expecting results in the order of σ_x ~60 μm, the fitting results provide a value around 50% larger (~90 μm). Note that the fitting quality is not optimum neither.

In order to improve the interference pattern, the priorities are to improve the instrumentation used to select the wavelength and polarization. The main points to improve are:

- **Polarizer:** We used a Melles-Griott FPG polarizer with a transmission ratio of about 30%. The presence of both σ and π-polarization from the bending magnet washes out the interference pattern. Thus, we are looking for a new polarizer with a more stringent transmission ratio.

- **Wavelength Filter:** We use typical dichroic color filters (green model – FD1G from Thorlab) with a pass-band of $\Delta\lambda$ ~80 nm). Again, this blurs out the interference pattern. The new wavelength filters are $\Delta\lambda$=10, 3, and 1 nm respectively (corresponding to the filters Thorlabs FL05632.8-10, -3, -1).

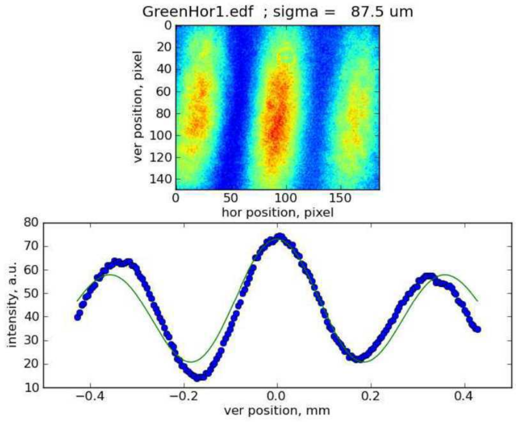

Figure 6: Interference pattern in the horizontal plane.

- **Reflective Optics:** Refractive lenses, as the one currently used in this set-up, introduces chromatic and dispersive effects. In order to avoid them, the use of reflective optics is foreseen.

5 Conclusions and outlook

In order to obtain reliable bunch by bunch emittance measurements at the optical hutch in BL34, two main constrains must be overcome: time and image resolution limitations related to the use of visible light.

The timing constrains are solved using the FGC from CERN, which is capable to provide a camera gating down to 3 ns. Using the existing electronical systems, we obtained images of 10 bunches. The gate is limited by the capabilities of the current triggering system provides. With the recently acquired pulse generator SRS-DG645, we shall be able to feed the FGC with a 3 ns gate with a repetition rate of every turn.

Nevertheless, the image resolution is still dominated by the limiting effects related to the visible light. We foresee to use interferometry measurements in order to overcome these limitations. In this regard, first test were carried out at ALBA and showed that few upgrades must be done to make precise measurements. This includes conventional optics instrumentation, (like polarizer or wavelength filters), but also the study of a possible improvement to our in-vacuum mirror: change the hardware to include a "full-mirror" with the proper water cooling system to avoid overheating.

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