ATF2 BEAM HALO COLLIMATION SYSTEM BACKGROUND AND WAKEFIELD MEASUREMENTS IN THE 2016 RUNS

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Abstract

A single vertical beam halo collimation system has been installed in ATF2 in March 2016 to reduce the background in the IP and Post-IP region. In this paper, we present the results of an experimental program carried out during 2016 in order to demonstrate the efficiency of the vertical collimation system and measure the wakefields induced by such a system. Furthermore, a comparison of the measurements of the collimation system wakefield impact with CST PS numerical simulations and analytical calculations is also presented.

INTRODUCTION

The ATF2 [1] facility was constructed to address two major challenges of the Future Linear Collider (FLC): focusing the beam to the nanometer scale using the International Linear Collider (ILC) Final Focus System (FFS) and proving nanometer beam stability. Undesired background due to beam halo hitting the beam pipe of some machine components could limit the performance and experiments of the machine. In order to control the beam halo and the losses, beam halo collimation systems are necessary. The design of such a systems is a complex balance between the efficiency needed, the wakefields induced which can compromise the beam stability and self-preservation.

In ATF2, background photons generated in the Post-IP showed to be limiting the performance of the Post-IP diagnostics. There was no dedicated beam halo collimation system in ATF2 although some apertures and a Tapered beam Pipe (TBP) installed in the high β-region were intercepting part of it. We have performed a feasibility design study of a vertical collimation system [2, 3] with the main objective of reducing the background photons in the ATF2 Post-IP. The system was constructed at LAL and installed in ATF2 in March 2016 [4].

In this paper, we present the results of an experimental program carried out during 2016 in order to demonstrate the efficiency of the vertical collimation system and measure the wakefields induced by such a system. These wakefield measurements were done to investigate the optimum operation mode of the vertical collimation system in terms of efficiency and acceptable wakefield impact. In addition, we performed a systematic benchmarking study of theoretical models, numerical simulations and measurements. The fact that there are discrepancies in the wakefield kick described in different analytical models for the same regime, in the models implemented in the tracking codes and between simulations and measurements (ESA (SLAC) 2001-2007 [5]) motivated our study. In addition, there are different analytical regimes (inductive, intermediate, diffractive) depending on the geometry of the jaws and beam parameters and when the parameters of the problem sit close to the limits the estimations are not accurate and numerical simulations and measurements are crucial. These benchmarking studies have contributed to the understanding of the applicability of the tools used to estimate such effect being essential for the design of the FLC collimation systems. The study presented on this paper applies for structures laying in the inductive geometric wakefield regime and long range resistive one.

WAKEFIELD MEASUREMENTS

Experimental Set-Up and Data Analysis Description

Wakefields are induced when a beam is passing through an accelerator component with an offset, Δy^c (see Fig. 1). In our experiment, in order to simulate this condition we move the vertical collimation system around the beam in a symmetric way keeping constant the half aperture, a, of the system but changing the collimator-center-beam offset and we measure the induced orbit changed in the downstream BPMs. This could be done because the collimation system jaws can be moved independently.

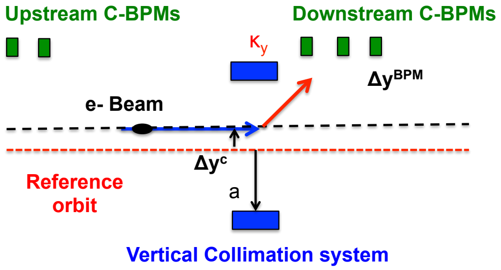

Figure 1: Experiment set up scheme for wakefield measurements.

The orbit variation at a downstream BPM, Δy^{BPM}, is related with the offset at the collimation system, Δy^c as:

$$\Delta y^{BPM} = R_{34} \frac{eq}{E} \kappa_y \Delta y^c \qquad (1)$$

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where R_{34} is the optics transfer matrix element, E is the nominal ATF2 beam energy, eq is the measured charge of the beam and κ_y is the wakefield kick we want to measure. For doing this, the ATF2 C-BPM system was used with expected resolution about 250 nm [6].

The expected orbit variation due to the wakefields induced by the vertical collimation system is at the level of the expected ATF2 orbit jitter. The method used is based on measuring the correlation between the upstream and downstream vertical collimation system C-BPMs explained in detail in [7]. This correlation is then used to predict the orbit at a downstream C-BPMs.

In a first step, we clean the orbit data. The zeros in charge are removed as well as the pulses with a position and charge value higher than 5 σ of the corresponding distribution. We subtract after the averaged orbit to all data in order to remove possible systematic offsets and we normalize the data to the charge. Then, we calculate the correlation matrix, X, that correlates the upstream, A, and downstream, B, vertical collimation system C-BPMs orbit as $AX = B$. Where A, has dimension of $(P \times M_{up})$ and B, has dimension of $(P \times M_{down})$ being P the number of pulses and M_{up} and M_{down} the corresponding number of upstream and downstream BPMs, respectively. We construct the A and B matrices with all data taken for the different vertical collimation system positions. Here, in order to reduce systematic errors in our measurements we have analyzed the orbit at the upstream C-BPMs for the different vertical collimation system offsets. In some cases, we observed a correlation between the upstream vertical collimation system C-BPMs, the orbit of those C-BPMs was not considered in the analysis.

Then, the X matrix is calculated as $X = A^{-1}B$. In order to invert the orbit matrix, A, the Singular Value Decomposition (SVD) method is used to easier this operation. In this operation, we apply a cut on the singular values lower than 10^{-4} to reduce the noise of the orbit signal.

In a second step, we average for all pulses the matrix, X, and we calculate what we called the residuals, R^i, for a given downstream C-BPM, i, for each collimator-beam offset, R^i, as:

$$R^i = \bar{A}\bar{X} - \bar{B}^i \qquad (2)$$

where $\bar{A}$ and $\bar{B}$ are the averaged orbit matrices for each collimator-beam offset. These residuals are equivalent to the Δy^{BPM} in Eq. (1). From the correlation of these measured residuals, R^i, and the collimator-center-beam offset, Δy^c, the vertical collimation system wakefield kick, κ_y, can be calculated by fitting our residuals plot to a function of the form of Eq. (1).

Wakefield Kick Measurements Summary

In total five shifts were dedicated to perform these measurements on the 20th, 24th and 27th of May, 27th of October and 1st of December 2016. In the first four shifts, the experiment was performed for a fixed vertical collimation system half aperture of 4 mm while in December the experiment was carried out for a 3 mm half aperture. During these shifts the energy of the beam was 1.3 GeV, the optics was the $(10\beta_x \times 1\beta_y)$ and the beam intensity was ranging from 0.75 to 1.1 $\times 10^{10}$ electrons. The bunch length, σ_z, was also measured in each shift using the Streak camera installed in the ATF DR. These measurements are essential in order to reduce the uncertainties in the comparison of the measurements with the analytical and numerical calculations. The bunch length measured for intensities higher than 0.75 $\times 10^{10}$ electrons was about 9.0 ±0.7 mm. As an example, from the data taken on the 24th of May and 1st of December, in Fig. 2 and Fig. 3 respectively, the correlation measured at $QD2AFF$ (top) and the calculated wakefield kick at the different C-BPMs were the correlation was observed (bottom) are shown.

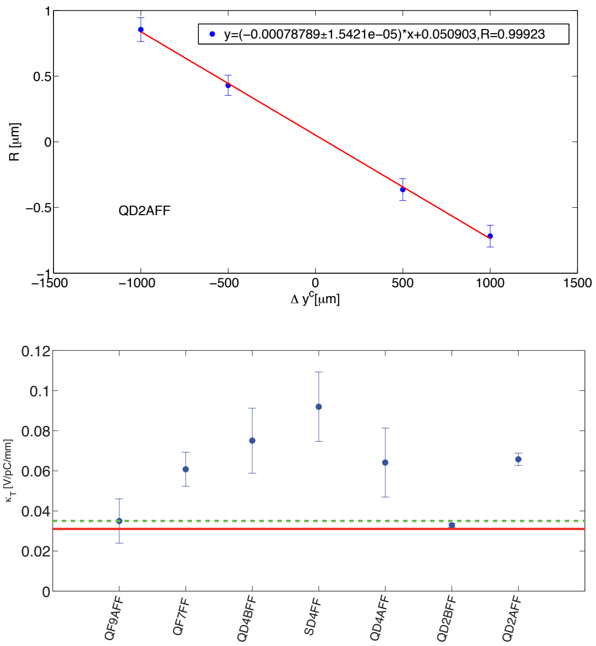

Figure 2: Measured R^i as a function of the Δy^c at $QD2AFF$ (top) and κ_y^i calculated at all C-BPMs downstream the vertical collimation system where the correlation was observed for 4 mm half aperture. Measurements from the 24th of May. The expected value calculated using the analytical models (in red) and from CST PS simulations (in green) are indicated for comparison for 9 mm bunch length.

The measurements of the wakefield kick induced by the vertical collimation system are in agreement with the associated error within the realistic numerical simulations performed with CST PS [8]. The benchmarking accuracy is at the 10% level. These wakefield measurements validate our CST PS simulations. In addition, the difference observed within measurements and analytical calculation of the jaws is about 20 %. Notice here, that the analytical calculations take into account only the jaws of the collimation system. The numerical calculations with CST PS, which are in agreement with measurements, have been performed for the ATF2 bunch length, the proper scaling to the ILC scenario has to be

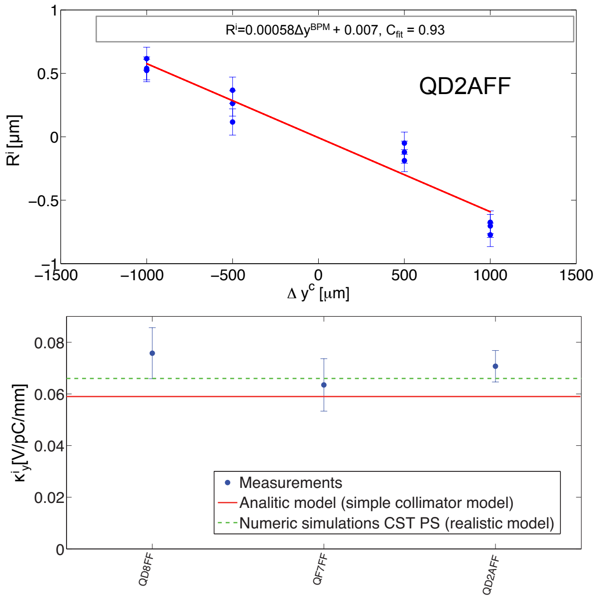

Figure 3: R^i as a function of the Δy^c at $QD2AFF$ (top) and κ_y^i calculated at 3 C-BPMs downstream the vertical collimation system fro 3 mm half aperture. measurements from the 1st of May. The expected value calculated using the analytical models (in red) and from CST PS simulations (in green) are indicated for comparison for 9 mm bunch length.

done in order to perform realistic simulation of the wakefield impact in such a case.

EFFICIENCY MEASUREMENTS

The vertical collimation system was designed with the main objective of reducing the background photons in the Post-IP region. The efficiency in reducing the background photons has been measured using the background monitor and the IPBSM Cherenkov monitor, both, located after the last bending magnet (BDUMP) of the ATF2 beamline. Furthermore, the efficiency has been studied in comparison with the TBP working as a kind of collimation system but with a fixed half aperture of 8 mm. Measurements were taken in the 18th of March, 17th of May and 19th of October 2016. During these shifts the energy was 1.3 GeV, the machine was operated at the $(10\beta_x \times 1\beta_y)$ optics and the intensity was ranging from 0.7-0.8 $\times 10^{10}$ electrons.

In Fig. 4, the background photons reduction as a function of the vertical collimation system half aperture from 3 to 12 mm is shown. In each position, the background was measured for 100 pulses and averaged. These measurements have been compared with the relative reduction of background photons generated in the BDUMP modeled with the tracking code BDSIM [9] reported in [4]. These calculations are depicted in Fig. 4 in red.

From these studies we could conclude that the Post-IP background photons are reduced when the vertical collimation system is closed more than 6 mm corresponding to a collimation depth of 15 σ_y. The relative reduction of background photons, $(\Delta\gamma CE)$, is about 60-80 % for the vertical collimation system closed to a 3 mm half aperture and the measurements are consistent over the three different run periods. The reduction of photons generated in the BDUMP was modeled using BDSIM showing relative good consistency with measurements. The TBP has been used in the past as a kind of collimation system but limited to a maximum collimation depth of 18 σ_y for a beam passing through the center of the device. In order to achieve the same impact the vertical collimation system has to be closed between 5- 6 mm corresponding to 15-18 σ_y. A symmetric collimation depth smaller than 18 σ_y is only possible using the vertical collimation system. Since February 2017, in order to perform new wakefield experiments a C-band cavity was placed at the location of the TBP and the vertical collimation system was successfully operated as the main collimation system.

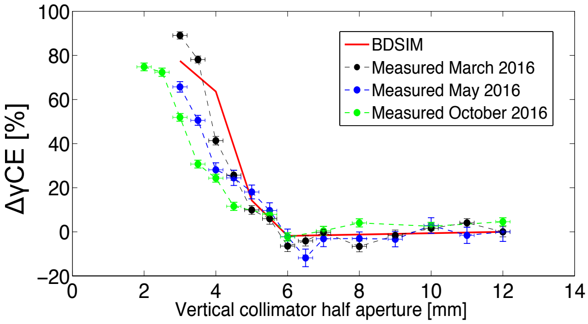

Figure 4: Comparison of the measured relative background photons reduction in the March, May and October 2016 runs in the Post-IP region with the BDSIM simulations.

PERFORMANCE SUMMARY

In Table 1, we summarize the performance of the ATF2 vertical collimation system in terms of efficiency and wakefields induced. The wakefield kick value measured corresponds to the averaged over all C-BPMs and shifts taken in 2016 weighted to the associated errors.

Table 1: Vertical Collimation System Performance Summary

[mm]	[%]		[V/pC/mm]		
a	$\Delta\gamma PC^{sim}$	$\Delta\gamma PC^{mea}$	κ_y^{an}	κ_y^{sim}	κ_y^{mea}
5	15	15	0.015	0.017	—
4	60	35	0.033	0.037	0.040±0.004
3	78	70	0.059	0.066	0.070±0.006

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