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Report on wakefields simulations and measurements in ATF2.

Executive summary:

The CSIC-IFIC, RHUL and KEK teams have performed a detailed analytical and numerical study of the wakefield impact of different devices in ATF2. These studies have been benchmarked and compared with wakefield measurements realized during different experimental campaigns in 2015 and 2016. This report will focus in particular on two aspects: the wakefield impact of a new vertical halo collimator installed in March 2016 and the dedicated "wakefield measurement campaign" in November-December 2016.

1. INTRODUCTION

Due to the interaction of the electromagnetic (EM) fields carried by the beam and the walls of the beam pipe, wakefields are induced. These fields have an impact on beam dynamics and can compromise the beam stability and performance of the accelerator. Therefore, it is crucial to characterize the elements of the beamline that can induce unacceptable wakefields. Benchmarking between analytical codes, numerical simulations and measurements of this effect is essential. This issue is relevant for FLCs (ILC and CLIC) demanding beam stability at the nm level, and it is in particular of paramount importance in ATF2 where an intensity dependence with these IP beam size is observed all along the operation periods – and a possible explanation is wakefields.

The wakefield impact of different devices like cavity beam position monitors (C-BPMs), optical transition radiation (OTR) monitors, tapered beam pipe (TBP) etc. present in ATF2 has been calculated in detail with electromagnetic solver programs (Gdfil and CST PS), and the beam dynamic impact has been simulated and measured. Recently a new vertical halo collimator has been installed in ATF2 in March 2016, a detailed calculation and simulation of wakefields has been made. The impact of such a device has been compared with others structures in ATF2. Furthermore, a study of the wakefield impact in the beam orbit and beam size has been performed with the tracking code PLACET. Some discrepancies from the point of view of definition of different analytical calculation wakefield regimes relevant for the ATF2 case has been encountered and solved, and the program has been modified accordingly. Corresponding measurements have also been performed in different 2016 ATF2 runs. The results of these measurements are reported and compared with the analytical calculations and simulations. The measurements are in accordance with the simulations within the error estimations.

The IP beam size intensity dependence problem due to wakefields has been addressed all along the ATF2 operation during the last years, and hardware modifications in the OTR chamber, the introduction of bellow electromagnetic shielding, a reduction of aperture steps and several other ideas have been realized to mitigate this persistent problem. A particular effort has been made in 2016 in order to solve this problem, and a dedicated "wakefield measurement campaign" has been made during the November-December 2016 operation.

In this report, we will focus on two aspects of this complex problem: first, the wakefield impact of a new vertical halo collimator installed in March 2016 in section 2, and, second, the results of the "wakefield measurement campaign" during November-December 2016 in section 3. Finally, the plans of this task are identified in section 4.

2. WAKEFIELD CALCULATIONS AND MEASUREMENTS OF A RECTANGULAR VERTICAL COLLIMATOR IN ATF2

2.1 Collimator wakefield calculations

In March 2016, a retractable vertical beam halo collimation system was installed in the Final Focus System of ATF2 with the main goal of reducing the background photons in the IP region to improve the IPBSM performance [3]. In Fig. 1, the mechanical design (top) and the real system installed in ATF2 (bottom) can be seen. The wakefield effect due to collimators could be very important since these devices have to be very close to the beam in order to efficiently clean the beam halo. This vertical beam halo collimation system was designed based on a preliminary design for the ILC spoilers [4]. The studies being performed for ATF2 will later be scaled to the ILC scenario in order to understand the performance and wakefield implication of this kind of system for the ILC.

One of the key issues on the design of the jaws of the collimation system for ATF2 was to minimize the wakefield effect. In order to estimate the collimator wakefield impact, analytical models and numerical simulations using CST PS were performed. These calculations have been compared with the impact of the reference cavity and the TBP previously studied in ATF2. The wakefield induced by the reference cavity installed in ATF2 between QM10AFF and QM10BFF was studied in detailed by means of numerical simulations using Gdfidl and measurements [1,2]. This structure was removed and changed by a currently installed tapered beam pipe (TBP) because of the induced high vertical wakefield impact observed at the IP. The reference cavity has a circular geometry with a half aperture transition from 8 to 19 mm without tapering (90º transition), while the TBP has a circular geometry with a fixed half aperture of 8 mm and a tapered angle of 7º. The TBP wakefield impact observed is negligible. However, discrepancies of about a factor 2 were obtained when comparing the simulations with the measurements, and studies are ongoing to understand these discrepancies.

The wakefield impact of the optimized collimation system is compared with the impact of the other two structures in Table 1. In addition, in Fig. 2 the wake potential in all planes for a bunch offset in the vertical plane of 1 mm and a vertical collimation system half aperture of 5 mm is depicted.

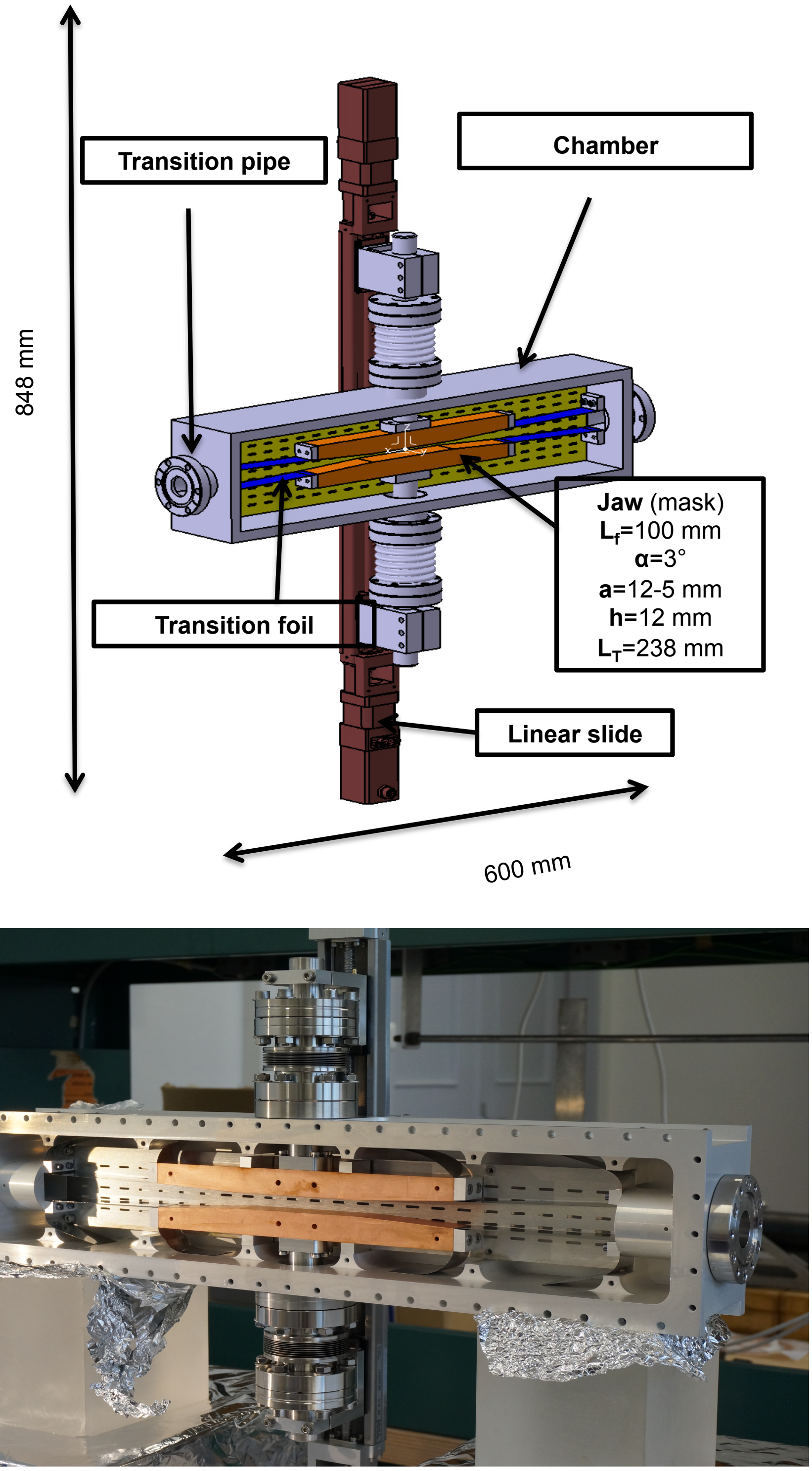

Fig. 1: Vertical collimation system: mechanical design (top) and real device installed in ATF2 (bottom).

Structure	Vertical half aperture [mm]	κ_y[V/pC/mm]
Reference Cavity	19	0.079
TBP	8	0.008
Vertical collimator	8	0.006

Table. 1: Wakefield kick impact comparison between the reference cavity, the TBP and the vertical collimator.

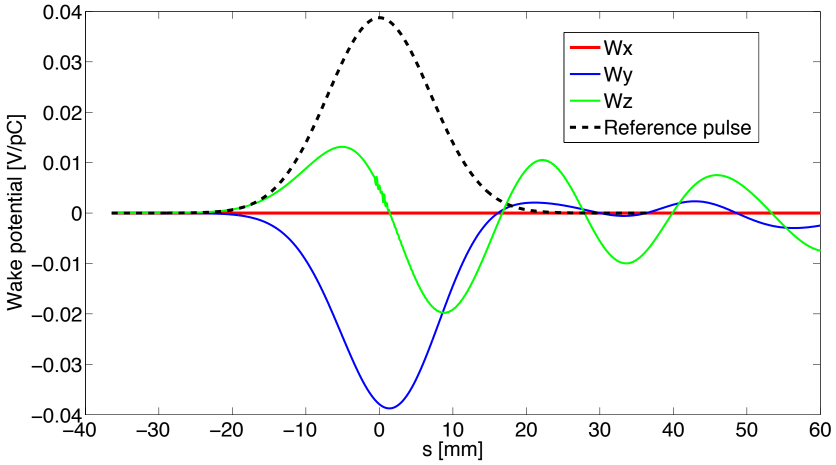

Fig. 2: Vertical collimation system wake potential for 5 mm vertical half aperture.

The very small vertical beam size at the IP in ATF2 and the IPBSM measurements determine the very tight tolerances in the FFS. Small perturbations on the orbit of each individual particle and the bunch yield to an increase of the measured beam size measured. Because of that the impact of the wakefields induced by the vertical collimation system has to be investigated. For that purpose the tracking code PLACET, which includes a module based on the analytic models introduced at the beginning of this chapter, has been used. The PLACET tracking results have been compared with the linear propagations of the calculated wakefield kick from CST PS. However, when using the tracking code PLACET, discrepancies were found between the results obtained with PLACET (v1.0.0) and the linear propagation of the wakefield kick calculated with CST PS. A detailed study was performed to identify the source of these discrepancies, and the problem was fixed in a new version of the tracking code PLACET (v1.0.1), as reported in Ref. [5].

This new PLACET version (v1.0.1) was used to study the wakefield effect induced on the ATF2 orbit and beam size at the IP, and all the results are published in Ref. [6]. The linear calculations and the PLACET simulations are compatible. In Fig. 3 the beam size growth at the IP is depicted as a function of the beam offset. For a vertical collimator half aperture of 5 mm, the beam size growth at the IP is about 16%, while for a vertical half aperture of 8 mm it is about 1% - both results being at a reasonable level.

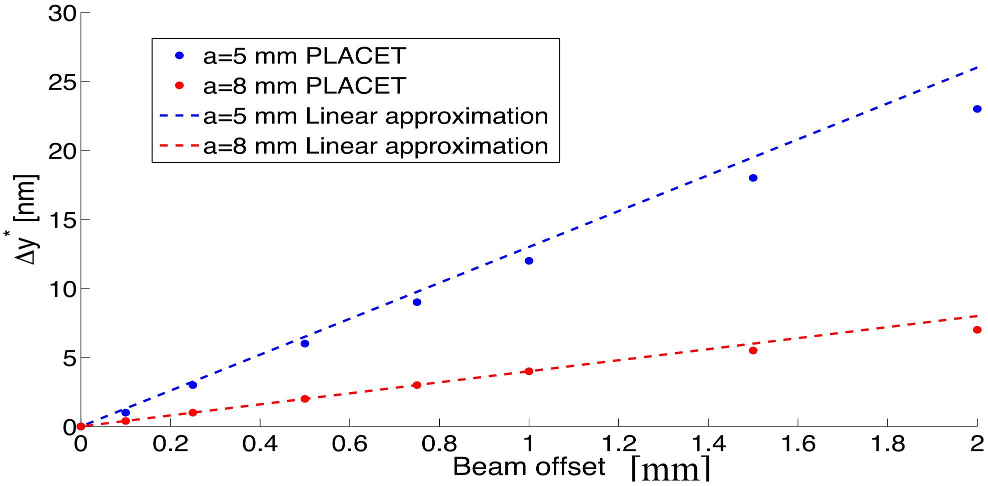

Fig. 3: Beam size growth due to the wakefields induced by the vertical collimation system.

2.1 Collimator wakefield kick measurements

In order to perform a benchmarking of the wakefield kick induced by the ATF2 vertical collimation system calculated by means of analytic models and CST PS numerical simulations, a measurement campaign has been carried out in 2016. The wakefield impact on the orbit has been measured by observing, in the downstream collimator BPMs, the variation on the orbit induced for different offsets of the collimation system with respect to the beam. First results were published in Refs. [6,7]. In addition, these measurements were performed for two different vertical collimation system half apertures corresponding to 3 and 4 mm. As an example, the variation of the orbit at the BPM QD2AFF as a function of the vertical collimation system offset is depicted in Fig. 4 for one set of measurements taken in November 2016. By using the slope of this measured correlation and the design optics of the ATF2 machine, the corresponding wakefield kick is reconstructed at each BPM. The analysis used was the same as used for the reference cavity BPM measurements described in Ref. [2]. An example of the wakefield kick reconstructed at different BPMs located downstream of the collimation system is shown in Fig. 5. Finally, in Table 2 we show, as a summary, the comparison of the ATF2 vertical collimation system wakefield kick calculated with the analytical models and CST PS numerical simulations with measurements. The measured value corresponds to the mean of the measurements performed in the different 2016 runs. The biggest error on the measurements comes from the uncertainty on the bunch length measurements perform with a Streak camera in the ATF DR. The numerical simulations of the complete collimation system performed with CST PS and the measurements are in agreement within the associated error. The discrepancy between the analytic calculation with the CST PS simulations and measurements can be understood since only the CST PS and the measurements take into account the complete collimation system (illustrated in Fig. 1). The analytic models only describe the rectangular jaws of the system.

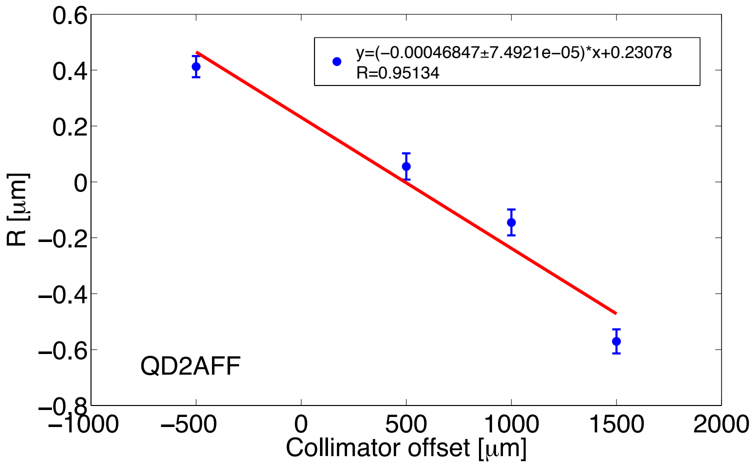

Fig. 4: Variation of the orbit at the BPM QD2AFF as a function of the collimator offset.

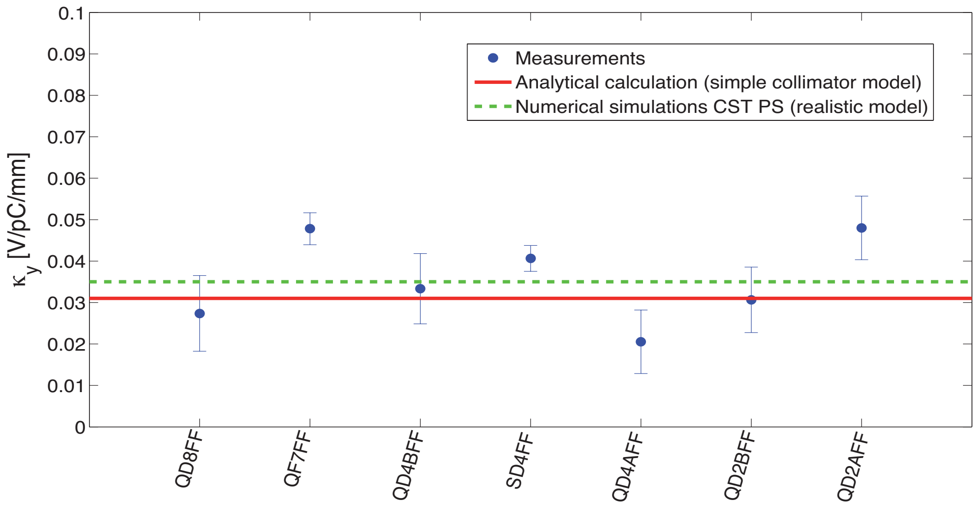

Fig. 5: Wakefield kick reconstructed at different BPMs downstream the collimator.

[mm]	[mm]	$\kappa_{T,y}$ [V/pC/mm]		
a	**σ_z**	**Analytic**	**CST PS**	**Measured**
4	9	0.033	0.037	0.038±0.002
3	9	0.059	0.066	0.063±0.002

Table. 2: Comparison of the ATF2 vertical collimation system wakefield kick calculated using analytical models and CST PS numerical simulations with the mean value of all measurements performed in the November/December 2016 runs.

3. ATF2 WAKEFIELD BEAM INTENSITY DEPENDENCE EXPERIMENTAL STUDIES IN NOVEMBER-DECEMBER 2016 [8]

The IP beam size dependence on bunch intensity has been a persistent problem in ATF2 during all the operation periods as it is shown in Figs. 5 and 6 for 2014 and 2015 and for different optics.

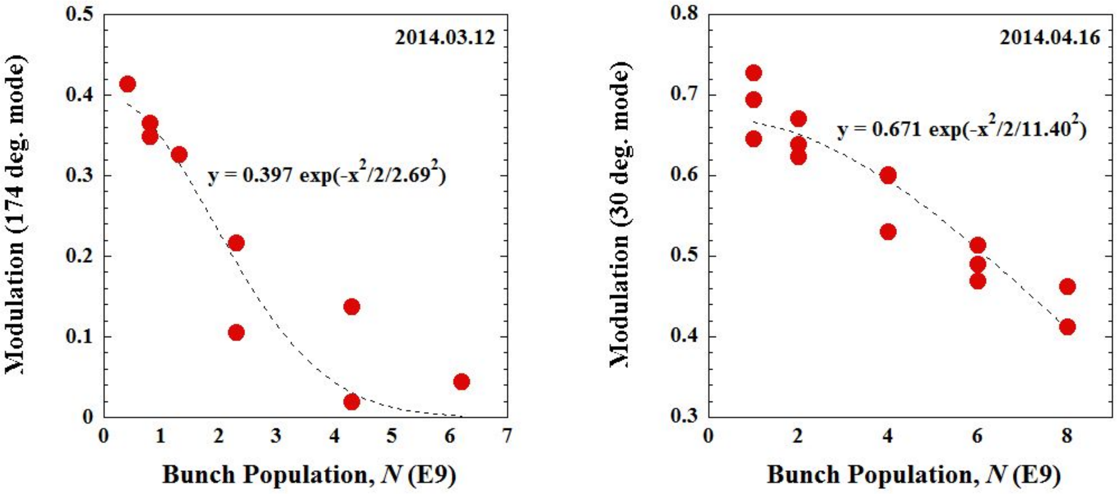

Fig. 6: IPBSM modulation as function of bunch population measured with a crossing angle of 174 degrees (left) and 30 degrees (right) in 2014.

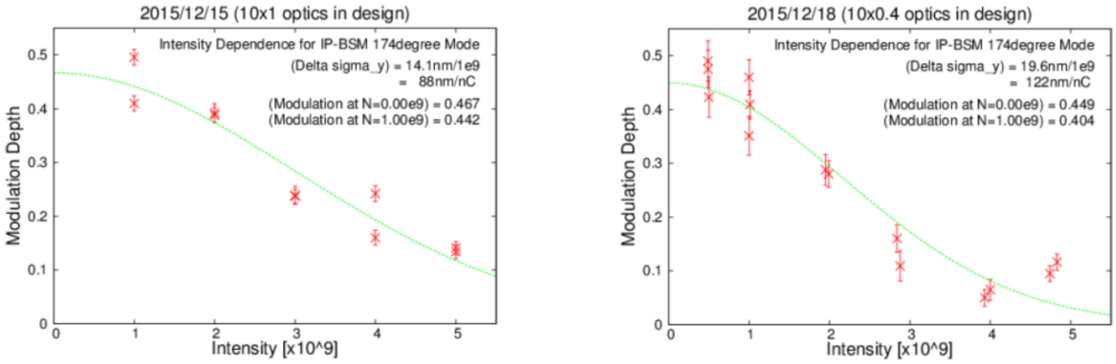

Fig. 7: IPBSM modulation as function of bunch population measured with crossing angle of 174 degrees and 10x1 optics (left) and 10x0.4 optics (right) in 2015.

Assuming $\sigma_y^2(q) = \sigma_y^2(0) + w^2q^2$ - with w the intensity dependence parameter in units of nm/10^9 - the smallest intensity dependence was observed in June 2014 with 9.7 nm/10^9 after the OTR chamber optimization (Fig. 6). In 2016 the intensity dependence was 14.1 nm/10^9 for normal optics $10\beta_x$ x $1\beta_y$ and 19.6 for $10\beta_x$ x $0.4\beta_y$ (Fig. 7). The effect of OTR2 monitor chamber position in the IP beam size is shown in Fig. 8

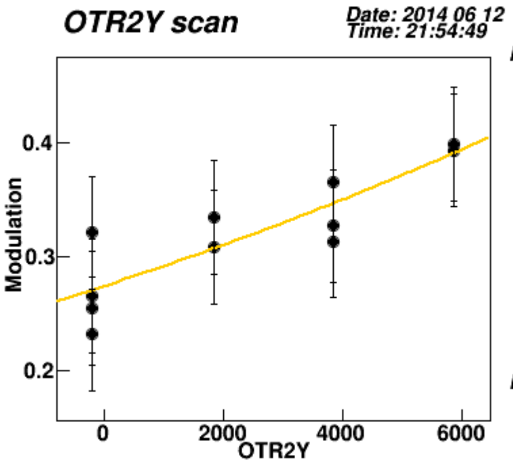

Fig. 8: IPBSM modulation measured with a crossing angle of 174 degrees as a function of the position of OTR2 for a bunch population of 3×10^9 *in June 2014.*

In order to study the induced wakefield effect and to mitigate its effect, an experimental setup consisting in a movable section including two reference C-band reference cavities, vacuum flanges and two bellows has been installed between QD10BFF and QD10AFF in the ATF2 beam line in a high-β region. The measured response to the position change of this device is 20% larger than the calculated value from EM simulations. Detailed information can be found in Ref. [1]. This movable section was able to compensate the static wakefield impact of other misaligned sources, but not the dynamic effect of the wakefield generated by orbit jitter.

In the extraction line, a 0.2-03σ orbit jitter is observed - a level of jitter that will increase the IP measured beam size by only 4%; but the effect on the IP angle (divergence) could be significant. Simulations of the intensity dependence with 20% jitter have been performed as shown in Fig. 9. The expected intensity dependence is 8.6 nm/10^9, the measured one is 15 nm/10^9, a factor 1.7 larger.

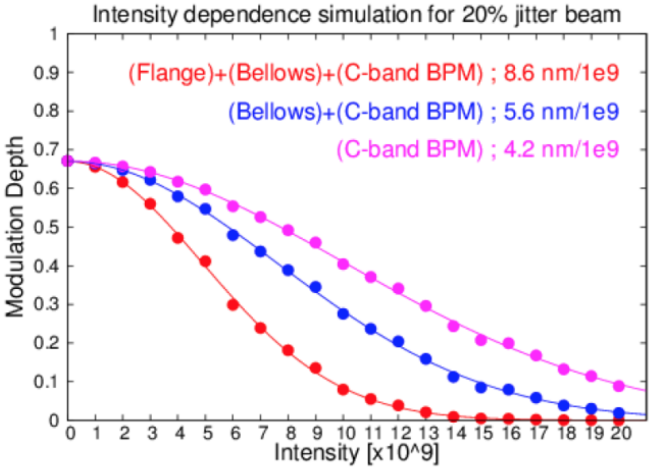

Fig. 9: Intensity dependence simulation of IPBSM modulation with 20% of jitter for different configurations of the movable section.

In Fig.10, measurements of the intensity dependence of the IP beam size and angle jitter for different optics configurations are shown. They are observed to be a factor 1.7 larger than the simulations.

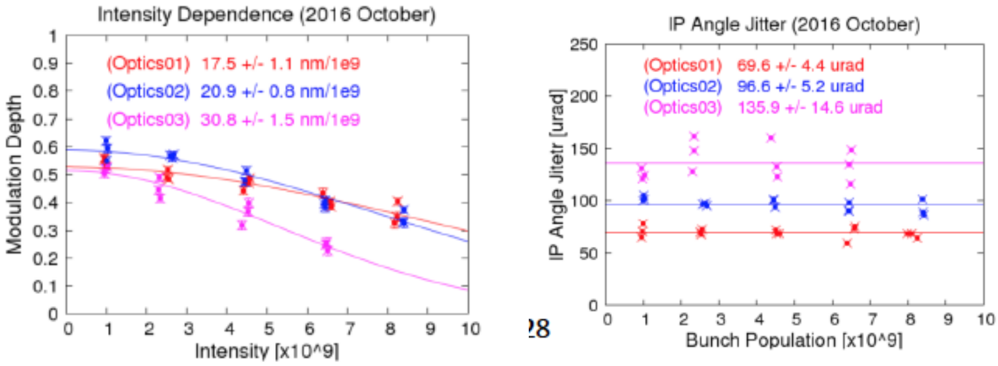

Fig. 10: IPBSM modulation measured in October 2016 with a crossing angle of 30 degrees (left) and IP angle jitter as function of bunch population of 0.3×10^9 for different optics configurations.

In November-December 2016 a dedicated wakefield study was performed. To reduce the wakefield sources, some cavity BPMs and some other components in high-β regions were removed. Furthermore, gaps of some flanges were shielded and a bending magnet chamber was changed. In this special configuration, “2D-scans” - consisting in setting different “angles at IP” by changing the steering magnet ZVFB1FF, monitoring the orbit change at MQD10AFF and minimizing the IP beam size by searching the position of MREF3FF (wakefield source on mover) - were performed as shown schematically in Fig. 11.
Figs. 12 and 13 show the results of the 2D-scans comparing the October (old configuration) and November (new configuration with reduced wakefield sources) measurements. Fig. 14 shows beam size intensity dependences comparing the October and November measurements.

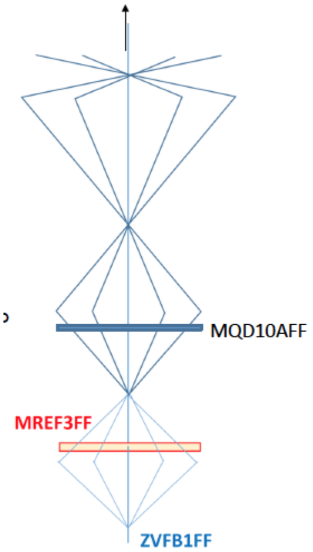

Fig. 11: Schematic layout of the 2D-scans procedure.

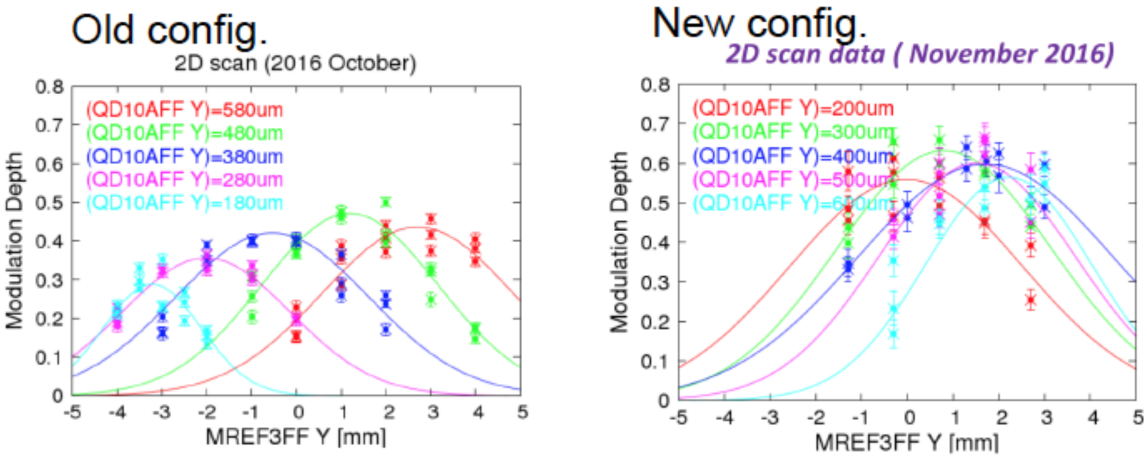

Fig. 12: IPBSM modulation measured with a crossing angle of 30 degrees as a function of the position of MREF3FF for October (left) and November (right) runs.

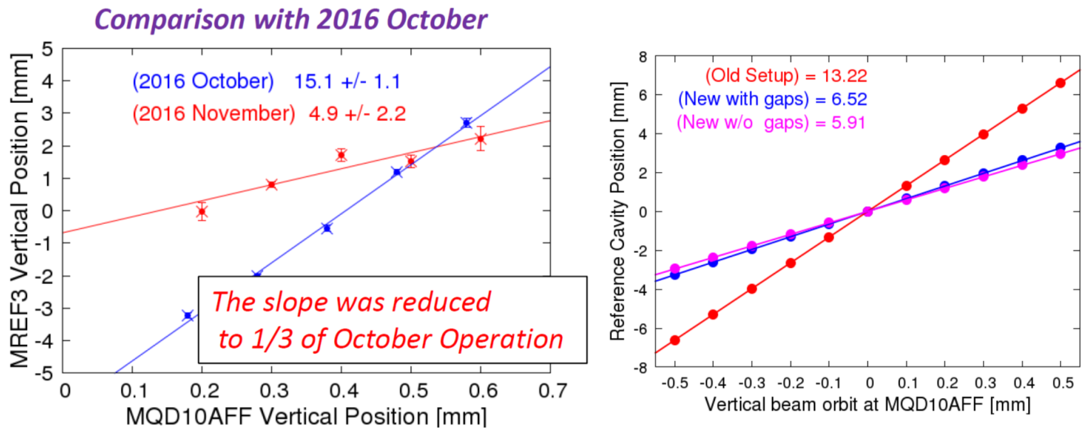

Fig. 13: Comparison of optimum vertical MREF3FF position as a function of vertical beam orbit at MDD10AFF measured (left) and simulated (right) for October and November runs.

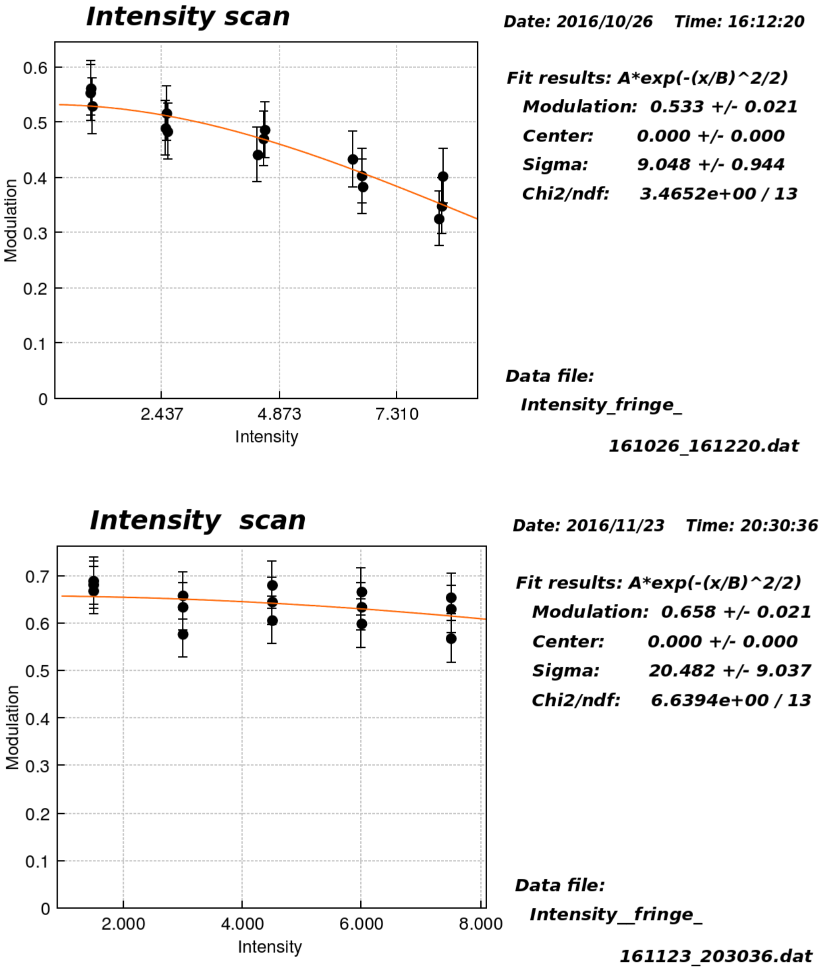

Fig. 14: Wakefield kick IPBSM modulation measured with a crossing angle of 30 degrees as a function of intensity for October (top) and November (bottom) runs.

In summary, a reduction of IP beam size intensity dependence operating with a reduced wake field source scenario of about a factor 0.3-0.5 has been observed in comparison with the 0.5 expected from calculations. Discrepancies could might be caused by an incomplete wakefield model, but intensity-dependence sources other than wakefields could not be excluded.

4. FUTURE PROSPECTS

The ongoing effort in modelling, measuring and mitigating the wakefield sources in ATF2 provides invaluable knowhow and experience in preparation for similar work at future linear colliders. The next step will be a detailed study of the ILC scaling and implications.

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