Grant Agreement No: 645479

E-JADE

Europe-Japan Accelerator Development Exchange Programme

Horizon 2020 / Marie Skłodowska-Curie Research and Innovation Staff Exchange (RISE)

DELIVERABLE REPORT

HALOCOLLBGDS-2

DELIVERABLE: 12

Document identifier:	E-Jade.Del.12-HaloCollBgds-2-v1.0
Due date of deliverable:	End of Month 24 (December 2016)
Report release date:	03/02/2017
Work package:	WP2: Nanometre Scale Beam Handling at the ATF
Lead beneficiary:	CNRS
Document status:	Final / public

Delivery Slip

	Name	Partner	Date
Authored by	P. Bambade A. Faus-Golfe	CNRS	01/02/17
Reviewed by	T. Schörner-Sadenius	DESY	02/02/17
Approved by	General Assembly		03/02/17

Deliverable:

Report on integrated simulation and evaluation of beam transport including beam instrumentation and charged particle backgrounds.

Executive summary:

During 2016, the CNRS-LAL and IFIC teams, in collaboration with KEK, have made significant progress on the modelling and generation of beam halo processes in the ATF damping ring and ATF2 beam transport line. Measurements of beam halo using the diamond sensor scanners already installed after the interaction point of ATF2, as well as with a YAG screen in the diagnostic section after the extraction, were compared with the modelling. In parallel, a collimator was designed, constructed and implemented to control the vertical beam halo near the interaction point of ATF2. With this collimator, background from bremsstrahlung photons in the instrumentation used to measure the beam size at the interaction point could be reduced. The background reduction factor with respect to collimator aperture was modelled with GEANT4, showing good consistency.

1. INTRODUCTION

A major issue in ATF2 and in linear colliders, as well as in many other accelerator facilities for high energy physics, is controlling the beam halo before the collision point. Beam halo consists of tails extending far beyond the Gaussian core of the beam. The halo can be generated during the acceleration process, through wake-fields and so-called dark current emission, as well as in the damping ring, through multiple Coulomb scattering of particles within bunches, scattering off the residual gas molecules in the vacuum chamber, or even scattering off photons from the black body thermal radiation present in the environment. The non-linearity in the optical transport can also enhance beam halo tails. From the experience at the Stanford Linear Collider (SLC) in the nineties and from more recent measurements at ATF, typically one per mille of the total bunch charge can populate the halo.

When the halo tail particles reach the vacuum chamber and start showering in the material, large numbers of secondary particles are produced. Places where these tail particles most likely get intercepted are in the last focusing quadrupole magnets, just before the collision point. In a future linear collider, such particle losses will be unacceptable near the collision point, as the produced secondary particles would have devastating effects on the experiments. For this reason, special collimation sections are planned upstream in the system to clean up the beam halo. The design of these sections uses assumptions and experience from the SLC concerning the population and propagation of halo particles.

Significant progress was made in 2016 on modelling and generating beam halo processes in the ATF damping ring and ATF2 beam transport line. Measurements of beam halo using the diamond sensor scanners already installed in 2015 after the interaction point of ATF2 [1], as well as with a YAG screen prepared by the KEK group in the diagnostic section after the extraction [2], were compared with the modelling. Vertical beam halo tails could be clearly identified with halo produced in the ATF ring through Coulomb scattering of beam particles off the residual gas molecules. Additional work presently on-going and planned in 2017-2018 is focused on understanding the origin of the halo in the horizontal plane, on exploiting a new calibration procedure defined for the diamond sensor to take into account saturation effects at high charge, and to design and implement an improved YAG screen monitoring system in the diagnostic section capable of simultaneous vertical and horizontal measurements.

At ATF2, there were initially no real collimators for the beam halo, although physical apertures at various locations along the beam line could intercept some of it. A dedicated collimator was successfully designed, constructed and implemented in 2016 to control the vertical beam halo near the interaction point of ATF2. With this collimator, background from bremsstrahlung photons in the instrumentation used to measure the beam size at the interaction point could be reduced. The background reduction factor with respect to the aperture of this collimator was modelled with GEANT4, showing good consistency.

2. REALISTIC BEAM HALO GENERATOR IN FOUR DIMENSIONS

A generator capable of simultaneously representing the Gaussian beam core with any chosen parametric distributions for the beam halo in the four coordinates of the transverse phase space (x, x’, y, y’) was prepared as a software tool for the simulations [3]. This tool, using normalised Courant-Snyder variables, describes all variables independently, with the proper correlations, while the transition between “Gaussian” and “parametric” distributions can be defined according to a criterion. Sufficient statistics is made available in the tails by suitable importance sampling and matching. An example of beam distributions obtained with this generator at the injection point of ATF2 is shown in Fig. 1.

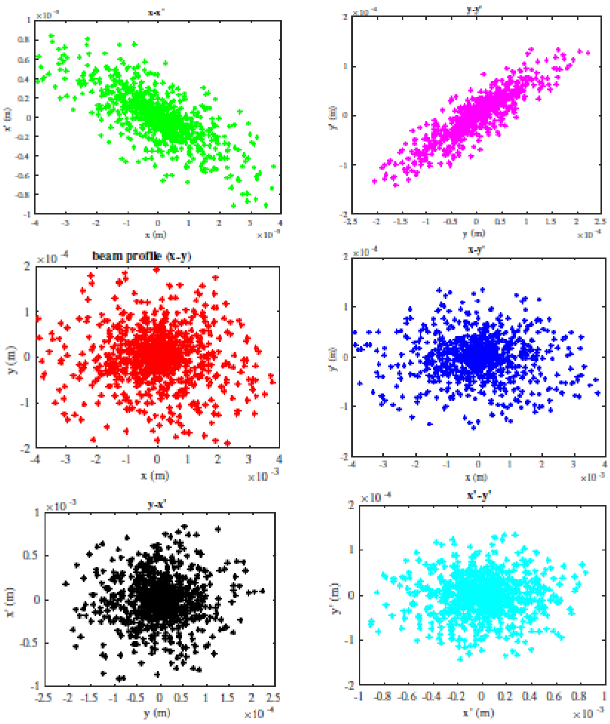


Fig. 1: Transverse simultaneous beam core and halo phase space distributions at the injection point to ATF2 obtained with a realistic four-dimensional generator.

3. VERTICAL BEAM HALO MODELING AND MEASUREMENTS

The generator described in the previous section was used as input to beam tracking in the optics of ATF2, in order to obtain predicted beam core and beam halo profiles at several locations along the beam line. Comparisons with measurements using a YAG screen installed in the diagnostic section after the extraction and with a wire-scanner and diamond sensor scanner installed after the interaction point are shown for the vertical dimension in Fig. 2 and Fig. 3, respectively [3]. The beam halo specified in the generator used a parametrization based on beam halo measurements performed in the past using wire-scanners in the dispersion-free diagnostic section [4]. In parallel, an analytical calculation of the beam halo produced by Coulomb scattering of beam particles in the ATF damping ring off the residual gas molecules was used to obtain theoretical predictions [5]. In such calculations, an inverse cubic dependence of the halo distribution with respect to the transverse phase space coordinates can be derived when integrating the differential cross section of the Coulomb scattering process, consistent with the parametrizations fitted on experimental data.

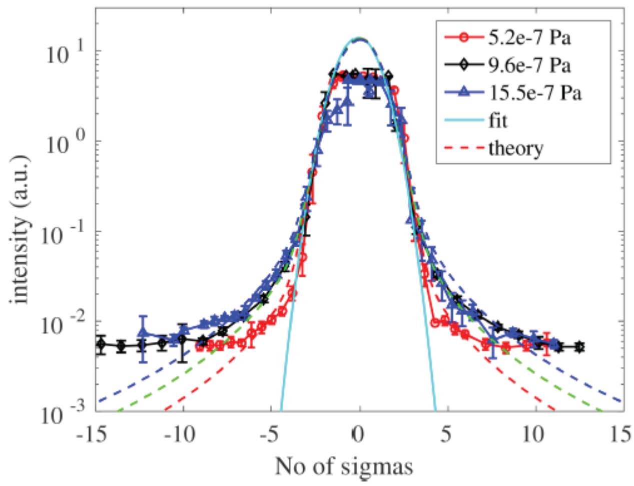


Fig. 2 Vertical beam halo distributions measured with a YAG screen in the diagnostic section after the extraction of the ATF ring compared with results from an analytical calculation, for three vacuum pressure levels in the ring. The Gaussian fit to the core is performed using a normalisation based on calibrating the saturation of the YAG screen.

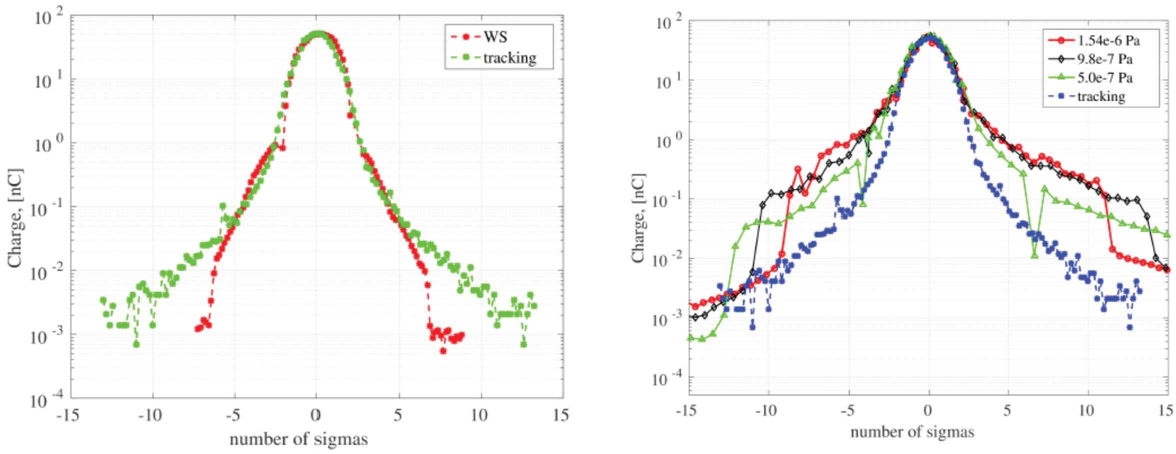


Fig. 3 Vertical beam halo distributions measured with a wire scanner (left) and diamond sensor scanner (right, for different residual gas pressures), compared with theory predictions based on tracking realistic beam halo generated at the input of ATF2.

It can be seen in Fig. 2 that the beam halo distributions measured with the YAG screen are consistent with the analytical predictions for the different residual pressure levels, and are enhanced when the pressure is increased. A similar enhancement with increasing pressure can be seen in the measurements of beam halo distributions at the diamond sensor scanner (see Fig. 3, right panel), however in this case the measurements are several orders of magnitude higher than the prediction obtained based on tracking realistic beam halo generated at the input. On the other hand, there is reasonably good agreement between the measurement and the tracking results at the wire scanner (see Fig. 3, left panel).

From these measurements, it could be concluded that:

- The vertical halo at ATF2 is dominated by scattering of beam particles off the molecules of the residual beam gas.
- The analytical calculation provides a reasonable estimate of vertical beam halo levels.
- There is no significant enhancement of the vertical beam halo when focused along the ATF2 beam line.
- The disagreement of beam halo levels with tracking results at the diamond sensor scanner must be of instrumental origin.

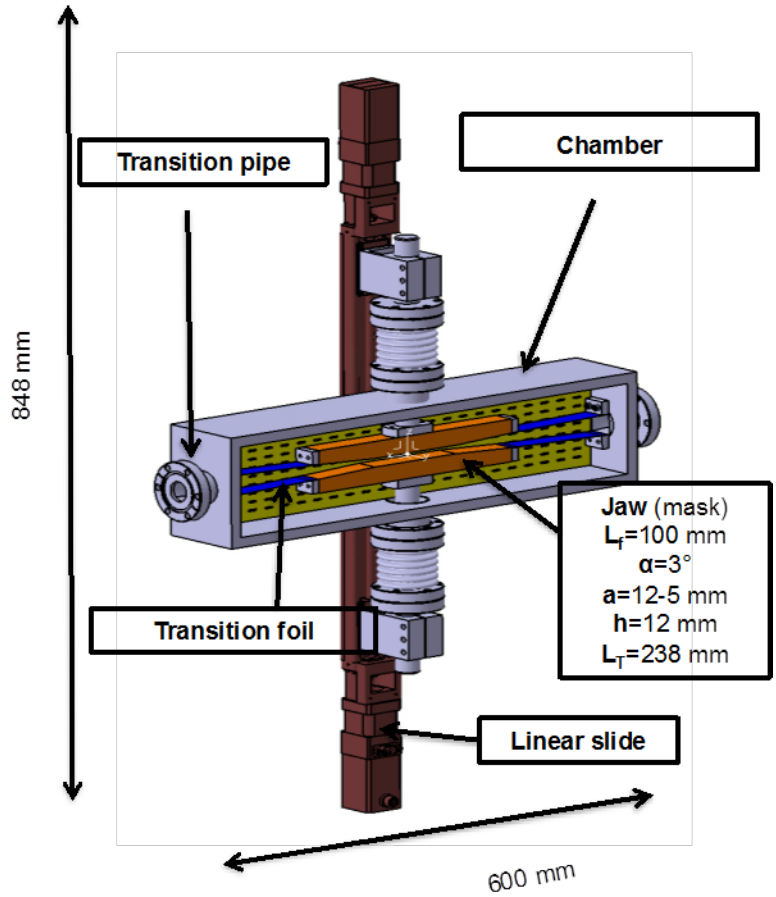
Further investigation of the last point has been made in recent operation, showing that the discrepancy can be largely explained by saturation effects that affect the signal collection in the diamond sensor [6] and depress the beam core and strongly bias the determination of its standard deviation, which is later used as normalization for the vertical coordinate. When using a beam core size extrapolated from the wire-scanner measurement, or when implementing a suitable calibration procedure for the diamond sensor, a much improved agreement could be obtained.

For a complete description of the above instrumentation and experimentation, we refer to the papers [1-6] listed in the references (Sect. 5).

4. BEAM HALO COLLIMATION AND BACKGROUND CONTROL

A dedicated retractable vertical beam halo collimation system was successfully designed, constructed and implemented in 2016 in the Final Focus System of ATF2, with the main goal to control the vertical beam halo near the interaction point of ATF2, in order to reduce the rate of bremsstrahlung photons in the instrumentation used to measure the nanometre beam size [7]. Fig. 4 shows the mechanical design (top) and the real system installed in ATF2 (bottom).

The installed device is efficient to collimate the vertical beam halo, as shown in Fig. 5 (left), where the displacement of the edges on both sides of the distribution are clearly follow the change in collimator aperture.



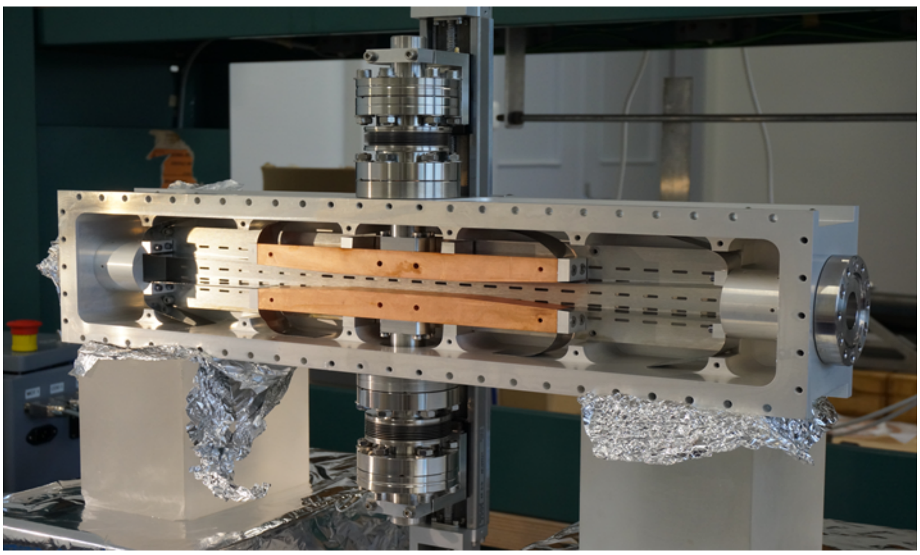


Fig.4 Vertical collimation system design (top) and real device installed in ATF2 (bottom).

Moreover, the beam line and interaction region were modelled with the GEANT4-based BDSIM toolkit [8]. As can be seen in Fig. 5 (right), the relative reduction with respect to collimator aperture in the rate of simulated bremsstrahlung photons at the photon collimator used to control the background in the beam size measurement shows good consistency with the actually measured background reduction within experimental uncertainties.

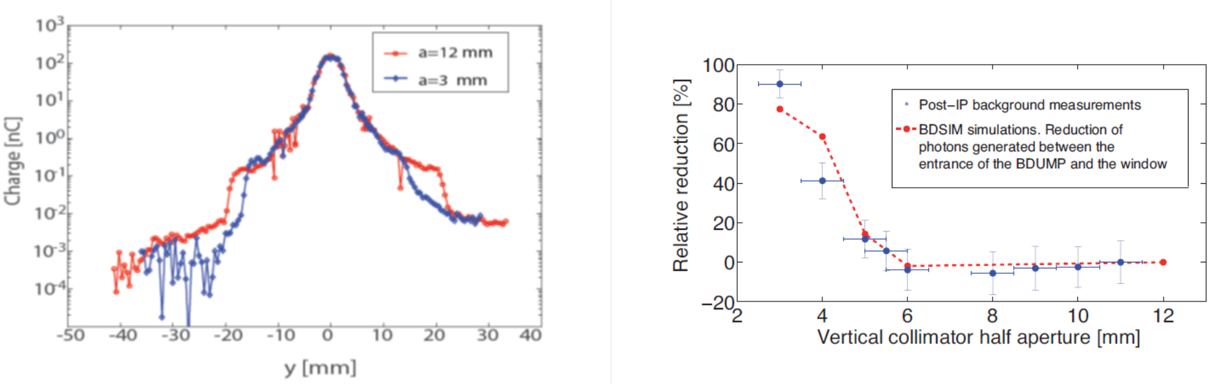


Fig.5 Vertical halo distribution measured with the diamond sensor scanner for two different collimator apertures (left). Comparison of relative reduction in photon background in the detector used for measuring nanometre beam sizes at the interaction point and in simulated bremsstrahlung photon rate at the photon collimator in front of the detector (right).

5. FUTURE PROSPECTS

Additional work presently on-going and planned in 2017-2018 is focused on understanding the origin of the halo in the horizontal plane, on exploiting the briefly mentioned new calibration procedure defined for the diamond sensor to take into account saturation effects at high charge, and to design and implement an improved YAG screen monitoring system in the diagnostic section, capable of simultaneous vertical and horizontal measurements. As part of characterising the relevant halo generating processes in the ATF ring, beam tracking simulations including elastic and inelastic Coulomb scattering off the gas molecules, as well as intra-beam Coulomb scattering, in the presence of radiation damping and quantum excitation effects, are also being developed.

The pursued and on-going efforts to model, measure and control beam halo and beam-induced backgrounds at ATF2 provide invaluable knowhow and experience in preparation for similar work at future linear colliders.

6. REFERENCES

JOURNAL ARTICLES

[1] S. Liu et al., "In Vacuum Diamond Sensor Scanner for Beam Halo Measurements in the Beam Line at the KEK Accelerator Test Facility", Nucl.Instrum.Meth. A832 (2016) 231-242

CONFERENCE PAPERS AND OTHER REFERENCES

[2] T. Naito et al., "Beam Halo Measurement Utilizing YAG:CE Screen", TUPB024, presented at IBIC 2015, Melbourne, Australia, 14-17 September 2015

[3] R. Yang et al., "Modeling and Experimental Studies of Beam Halo at ATF2", MOPMB008, presented at the 7th International Particle Accelerator Conference (IPAC 2016), Busan, South Korea, 9-13 May 2016

[4] N. Fuster-Martinez et al., "Measurement of Beam Halo Transverse Distributions Using Wire Scanners at ATF2", Technical Note ATF-14-01

[5] D. Wang et al., "Analytical Estimation of ATF Beam Halo Distribution", THPOR045, presented at the 7th International Particle Accelerator Conference (IPAC 2016), Busan, South Korea, 9-13 May 2016

[6] V. Kubytstyi et al., "Modeling/Measurement Comparison of Signal Collection in Diamond Sensors in Extreme Conditions", WEPMN007, presented at the 6th International Particle Accelerator Conference (IPAC 2015), Richmond, Virginia, USA, 3-8 May 2015

[7] N. Fuster-Martinez et al., "Commissioning and First Performance Studies of a Single Vertical Beam Halo Collimation System at ATF2", THPOR030, presented at the 7th International Particle Accelerator Conference (IPAC 2016), Busan, South Korea, 9-13 May 2016

[8] http://twiki.ph.rhul.ac.uk/twiki/bin/view/PP/JAI/BdSim