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Report on halo measurement and control using diamond sensor and collimators.

Executive summary:

The CNRS-LAL team, in collaboration with IFIC and KEK, have performed initial beam halo measurements at the ATF2 during the end of 2014 and in 2015, using a set of newly commissioning single crystal CVD diamond sensor scanners installed after the BDUMP bending magnet, a few meters after the final focal point of the optical system.

Measurement data were collected and analysed both in the horizontal and vertical planes, for several conditions of the beam optics (e.g. different demagnification factors of the optics), settings of a tapered beam pipe presently used as collimating device, and different vacuum pressures in the ATF damping ring.

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 a 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.

At ATF2, there were initially no real collimators for the beam halo, although physical apertures of the vacuum chamber at various locations along the beam line do intercept some of it. Dedicated collimators have now been prepared by CNRS-LAL and IFIC and a first set will be installed in March 2016 for the vertical beam halo. In recent experiments, a specially prepared tapered beam pipe section, positioned on a moveable stage, has also been used to collimate beam halo and mitigate backgrounds in the instrumentation used for beam size measurements.

For measuring beam halo distributions and assessing the effect of collimator and other apertures, a set of new diamond sensor scanners has been installed and commissioned at ATF2. Located behind a bending magnet (BDUMP), a few metres after the main focal point of the optical system, where beams are now routinely focused down to vertical sizes as small as 40 nm, they allow simultaneous measurements of the beam core and beam halo to be performed with an unprecedented large dynamic range of 10^6.

2. IN-VACUUM DIAMOND SENSOR SCANNER AT ATF2

A large signal range from 10^2 to 10^8 e^- / mm^2 is typically needed to measure both beam halo and beam core at ATF2. To first approximation the signal strength is proportional to the metallised surface of the electrode on the diamond. Four strips are used to cover this large dynamic range (see Fig. 1). The two strips designed for beam halo scanning are on the two outer sides, with dimensions of 1.5 mm × 4 mm, and the other two designed for the beam core scan are in the centre, with dimensions of 0.1 mm × 4 mm.

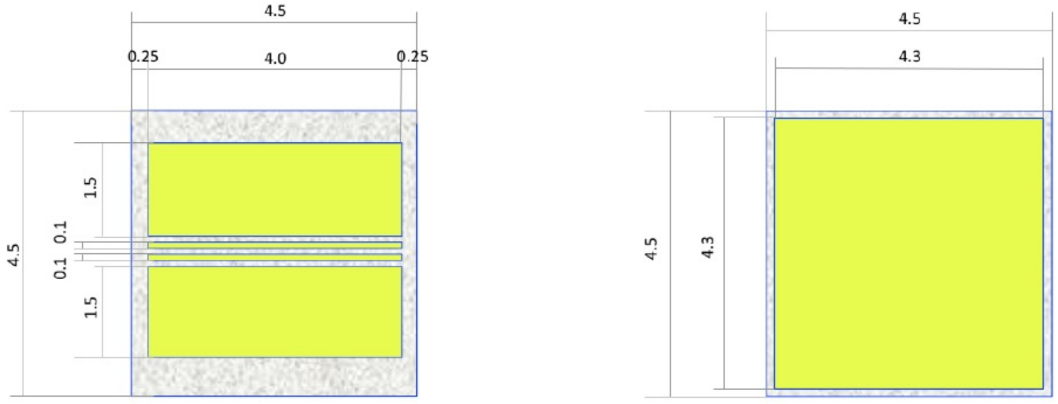

Fig. 1: Diamond sensor with four strips: top side (left) and bottom side (right)

For the in-vacuum application a ceramic PCB is used. The ceramic PCB uses a silver-platinum conductor produced in thick-film technology. The PCB and the electrical circuit for the diamond detector are shown in Fig. 2. A low-pass filter and charging capacitors are mounted on the backside of the ceramic PCB. The parameters of this circuit were set based on the following considerations:

- The cut-off frequency for the high voltage power supply should be as low as possible to maintain the stability;
- The amount of charge stored on the capacitors should be large enough for measurements of large beam intensities, up to ~1 μC on the narrow strips;
- The charging time constant should be small to enable separating successive bunches, the bunch repetition rate being 3 Hz at ATF2;
- The simulated cut-off frequency for the present circuit is 8 Hz with a 500 μC maximum stored charge at 500 V and the charging time constant is 44 ms. These values can fulfill our requirements listed above.

The diamond sensor is designed to be installed in vacuum with a holder to scan the beam and beam halo. The whole setup is 0.8 m long and can be oriented either horizontally or vertically to scan in different axes. Fig. 3 shows the layout of the diamond sensor with the PCB on the holder and the motor used for the horizontal scan. The vacuum chamber with an inner diameter of 72.1 mm is connected to the beam pipe (diameter of 63 mm) and installed after the BDUMP bending magnet at ATF2 via two DN63CF flanges.

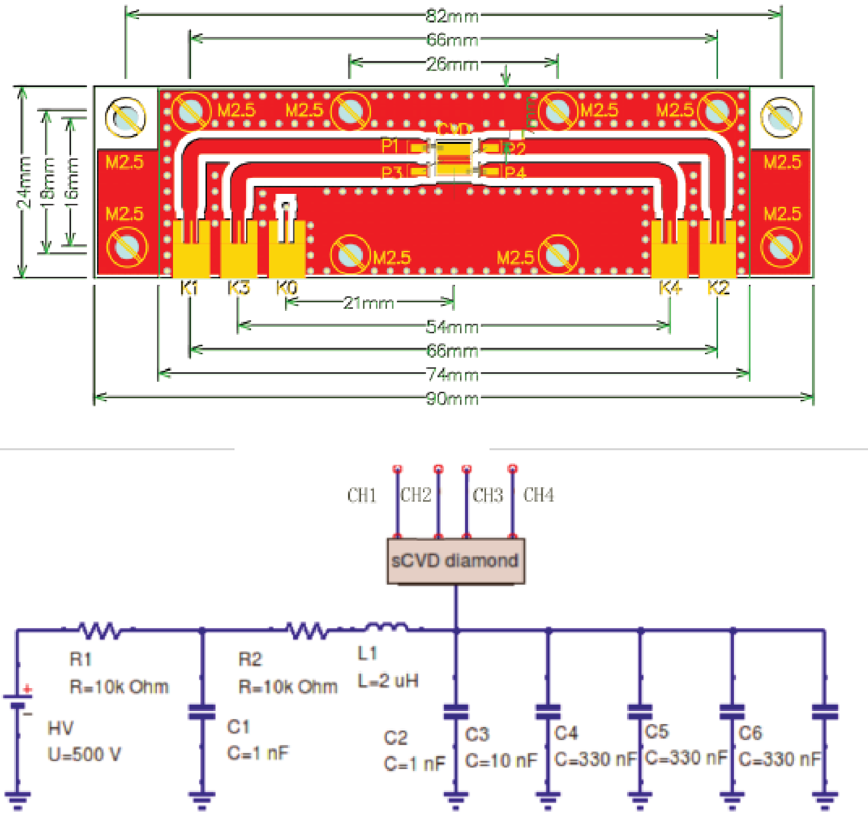

Fig. 2: Layout of the PCB (top) and electronic circuit (bottom)

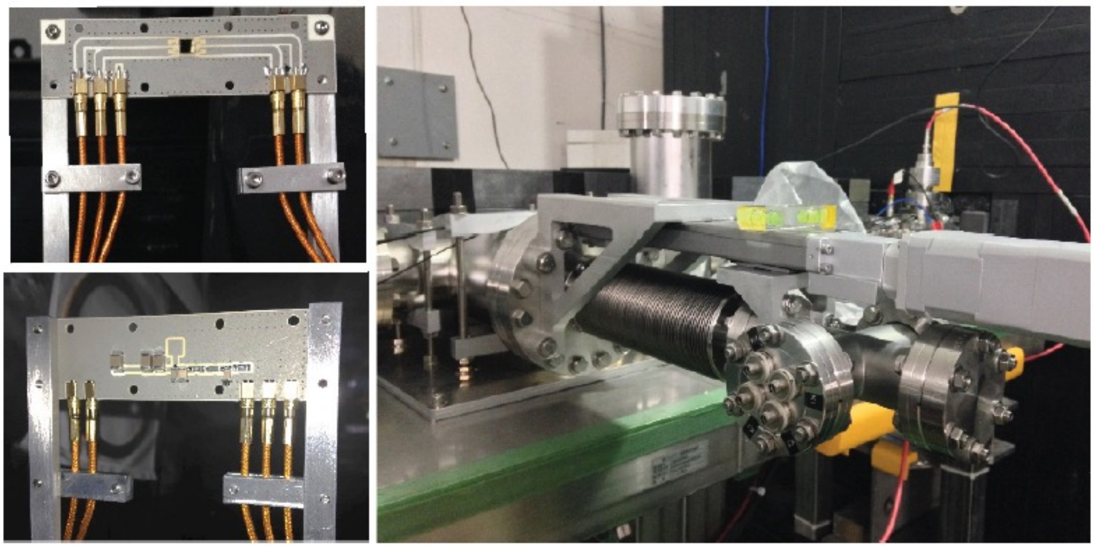

Fig. 3: Layout of the diamond sensor with the front side (upper left) and back side (lower left) of the PCB and the motor used for the horizontal scan (right)

3. BEAM CORE AND BEAM HALO MEASUREMENTS

First beam halo measurements were performed in both horizontal and vertical planes to check the effect of apertures along the beam line, as well as to study the horizontal beam halo dependence on the beam intensity and the vertical beam halo dependence on the vacuum level in the ATF damping ring.

Examples of combined beam core and beam halo distributions are shown in Fig.4 in the horizontal (left) and vertical (right) directions, respectively. The corresponding measured beam sizes for the beam core are ~1.4 and ~1.46 mm. The sharp edges in the vertical scan were identified as resulting from the vertical aperture of the vacuum chamber inside the BDUMP bending magnet immediately upstream of the diamond sensor.

Experiments were also performed moving the tapered beam pipe presently used as collimating device towards the beam. A clear edge could be obtained on the upper part of the vertical halo distribution, with a position following the motion of the tapered beam pipe, while on the lower part no effect could be found, indicating a possible misalignment of the beam.

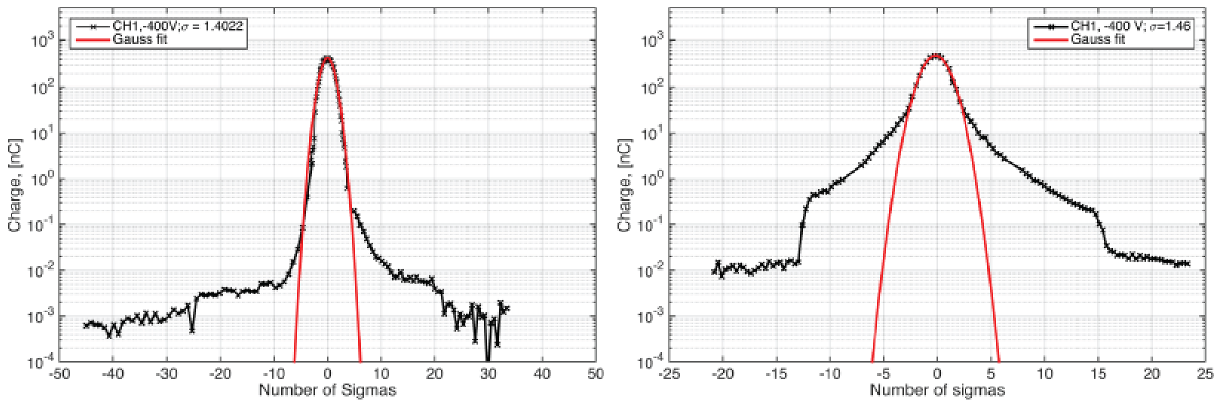

Fig. 4 Measured beam core and beam halo distribution using diamond sensors at ATF2

By modelling the beam halo and its propagation along the beam line, the role of the optical demagnification on the halo shape was also confirmed. Parameterizations of the distributions were moreover later obtained and compared with results from past measurements using wire-scanners, both in the present ATF2 beam line and in the old extraction line of ATF, showing good consistency.

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

4. FUTURE PROSPECTS

The immediate plans for this task include:

- Installation of a dedicated vertical halo collimator, with independent control from both sides.
- Installation of a similar collimator device for the horizontal direction.
- Experimentation with the collimators to control the beam halo in both directions, using the diamond sensors as diagnosing instruments.
- Experimentation with the collimators to reduce bremsstrahlung photon backgrounds in the instrumentation used to measure small beam sizes at the optical focal point, for increasing magnifications of the optical system.
- Modelling of halo propagation using MADX tracking code and of the bremsstrahlung photon background using BDSIM/GEANT4.
- Comparison of beam halo shapes with theoretical models for halo generation in the ATF damping rings, especially from Coulomb scattering of beam particles off the residual gas.

The on-going effort modelling, measuring and controlling beam halo at ATF2 provides invaluable knowhow and experience in preparation for similar work at future linear colliders.

5. REFERENCES

JOURNAL ARTICLES

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