Propagation of a beam halo in accelerator test facility 2 at KEK *

BAI Sha(白莎)[1] P. Bambade[2] GAO Jie(高杰)[1]

[1] Institute of High Energy Physics (IHEP), Beijing 100049, China
[2] LAL, Univ Paris-Sud, CNRS/IN2P3, Orsay, France

Abstract: The beam halo is a major issue for interaction region (IR) backgrounds at many colliders, for example, future linear colliders, B factories, and also it is an important problem at ATF2. In this paper, we report on the halo propagation along the ATF2 beam line with realistic apertures, the nonlinear optics influence on the increasing number of halo particles input is analyzed, and the transmitted halo particles distribution just before the last BPM is then described, the results from which will benefit the Compton recoil electrons measurement.

Key words: ATF2, beam halo, Compton scattering, Shintake monitor

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1 Introduction

The ATF2 project is the final focus system prototype for the ILC and CLIC linear collider projects, aiming at reaching 37 nm vertical beam size at the interaction point (IP) [1]. The Shintake monitor plays an important role in the measurement of the nanometer scale beam size. For the Shintake monitor, background suppression of the gamma detector is a very severe problem because the energy of the signal photon is much lower than the beam energy. Beam halo scattering with the beam pipe by bremsstrahlung is the major background in ATF2 [2]. We studied the propagation of a halo in the presence of realistic apertures for our present optics configuration, which has a different β^* compared to the original ATF2 design assumed in previous Beam Shintake Monitor (BSM) studies, and also some distortions from the recent special tuning for multipoles. This will be useful both for understanding the backgrounds in BSM, and for the understanding of the aperture requirements for any upgrades in future (e.g. ultralow β^* new final doublet quadrupoles$\cdots$) and also for the planned halo / Compton recoil measurement program.

In this paper, the realistic apertures along the ATF2 beam line are first reported. A halo generator using the parameterisations from Suehara's past halo measurements and also some of the input phase space correlations is used. Halo propagation along the ATF2 beam line with realistic apertures is then analyzed, including the nonlinear optics influence on the increasing number of halo particles input, and also the transmitted halo particles distribution just before the last BPM, which may have influence on the Compton recoil electrons measurement.

2 Apertures along the ATF2 beam line

The apertures along the ATF2 beam line are measured on the outer diameters of various pieces of beam pipes. Without measuring the exact position of the transitions or the details of various flange structures and bellows, some general results are obtained with centimeter scale. Most of the beam pipes are of circular cross-sections, but a few of them are of square ones with width and height. The beam pipe thickness is assumed to be 1 mm, and should be subtracted by the measured outer diameter. The actual apertures measured along the whole ATF2 beam line from start to IP are shown below:

As can be seen from Fig. 1, the tightest apertures are from the C-band BPMs attached to each quadrupole and sextupole in the final focus line, which are 20 mm in diameter, while the beam pipe before and after each C-band BPM is 27.5 mm in diameter. In the final doublet there are wider S-band BPMs with 20 mm in radius.

3 Halo generator

The charge distributions of the accelerator beams can be separated into two parts: the beam core, which usually has Gaussian distribution, and the beam halos, which have much broader distributions than the beam cores. In ATF and linear colliders, the halo population is about $1/10^3$.

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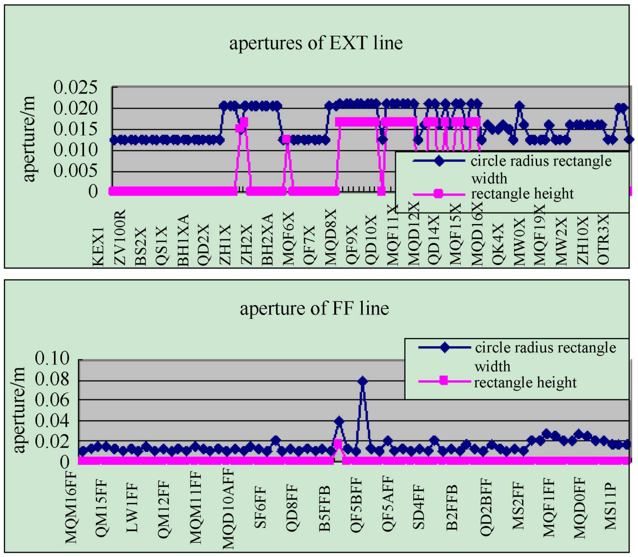

Fig. 1. Apertures of the beam pipe in the ATF2 extraction line and the final focus line.

A halo generator was based on the charge distribution measurement of a beam halo in the old ATF extraction line by Suehara in 2007. The measurement results show that the charge distribution in the beam center of $<3\sigma$ range is well approximated by a Gaussian, while in the region of $>3\sigma$, the deviation from the central Gaussian is quite large and will be treated as beam halo. It is assumed that the halo distribution in both vertical and horizontal directions follows the -3.5th power function until 6σ, and for outside 6σ the vertical distribution follows the -2.5th power function while the horizontal distribution still follows the -3.5th [3].

$$\begin{aligned} \rho_{\mathrm{h1}} &= 2.2\times10^{9}\times x^{-3.5} \ \text{(horizontal and vertical until } 6\sigma), \\ \rho_{\mathrm{h2}} &= 3.7\times10^{8}\times x^{-2.5} \ \text{(vertical outside } 6\sigma), \end{aligned} \tag{1}$$

where x is the distance from the beam center as a unit of σ.

The halo generator for the input beam distribution could be generalized to all 4 dimensions of phase space including all σ_{ij} correlations (i, j=1, 2, 3, 4), using the Courant-Snyder invariant [4], but without coupling between (x, x') and (y, y') planes. It correctly treats the correlations between x and x' and between y and y', based on the usual equation with the sigma matrix, and so it can accommodate non-zero input α values.

The initial halo energy spread from the damping ring (DR) is assumed to be the same as the core beam ($\mathrm{d}p/p$=0.08%).

4 Halo propagation along the ATF2 beam line

The study of the propagation of halo in the presence of realistic apertures was done for the nominal BX2.5BY1 optics configurations (β_x^*=0.01 m, β_y^*=0.0001 m), which have different β^* compared to the original ATF2 design, caused by some distortions from the recent special tuning for multipoles [5]. Diameters of the beam transportation pipes are designed such that the beam core does not hit the beam pipes. However, in some parts of the ATF2 beam line, the beam size is enhanced by the optics and a part of the beam halo can hit the beam pipes, which emits bremsstrahlung photons [3]. In MADX tracking [6], these halo particles will be lost.

4.1 Halo particles transmitted at C-band BPMs

As can be seen from Fig. 1, the tightest apertures in the ATF2 beam line are from the C-band BPMs attached to each magnet in the chromaticity correction system (CCS). They are only 10 mm in radius. Halo propagation along these positions with realistic apertures is shown below:

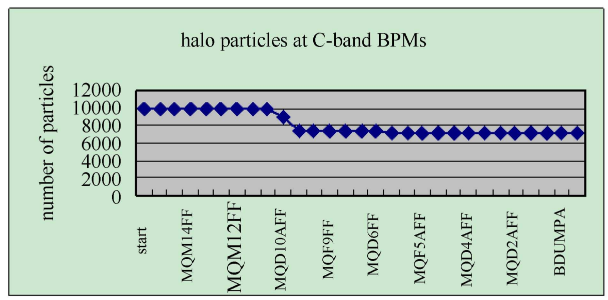

Fig. 2. Halo particles transmitted at C-band BPMs.

With 10000 halo particles which extend from 3σ to 20σ as input, the halo particle losses are concentrated on the first two C-band BPMs (MQD10AFF & MQF9BFF) where β_x and β_y have peaks, which is shown in Fig. 2.

While with the increase of halo particles from 20σ to 40σ and 60σ, which can be seen in Fig.3, big differences appear in the transmission probability, because of the initial losses upstream the two main ones at MQD10AFF and MQF9BFF and also because of other neighboring apertures where the β functions are large too, but not as large as MQD10AFF and MQF9BFF.

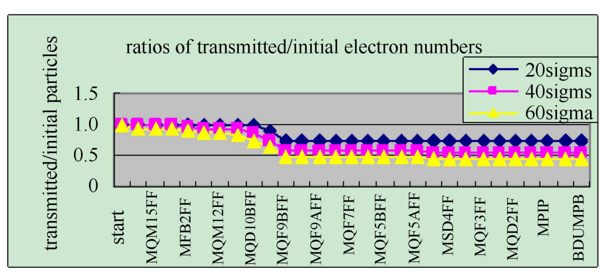

Fig. 3. The ratio of transmitted/initial halo particles with input halo particles 20σ, 40σ and 60σ.

4.2 Non-linear optics effect

The existence of the non-linearity of the optics may have influence on the ratio of transmitted electrons to initial electrons, which are the reduction factors as a function of the element along the whole beam line.

The non-linear optics effect was checked by the initial number of electrons which are shown in Fig. 4.

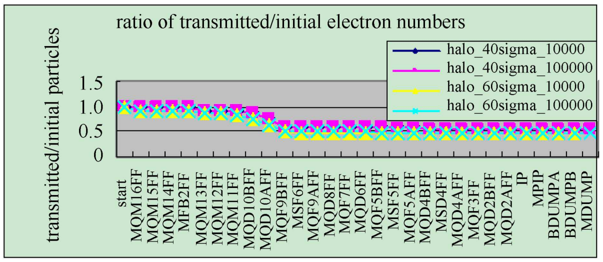

Fig. 4. Non-linear optics influence on the ratio of transmitted/initial electron numbers.

It seems that the ratio of transmitted/initial electron numbers remains almost the same of 10000 and 100000 particles depending on the number of sigmas generated in the initial phase space. The little difference of ratios may indeed be some tiny non-linear effects due to the sextupole coupling terms.

4.3 Halo distribution at the last BPM before DUMP

Since halo population is poorly known, this involves various mechanisms: "dark current", wake-field, non-linearity, multiple intra-beam Coulomb scattering, scattering off residual beam gas and thermal photons, very low Pt t-channel physics processes[1)]. A radiation hard diamond sensor for high flux particle detection using fast remote read-out [7] is proposed and will be used to measure the beam halo and Compton electron recoil spectrum in the ATF2 post-IP beam line[2)], which is quite near the last BPM (MDUMP) and is about 1.5 m before DUMP. Below is a sketch map of the ATF2 post-IP region.

At the IP where the Shintake monitor is installed, the Compton interactions occur directly between electrons of the beam and optical wavelength photons from the laser

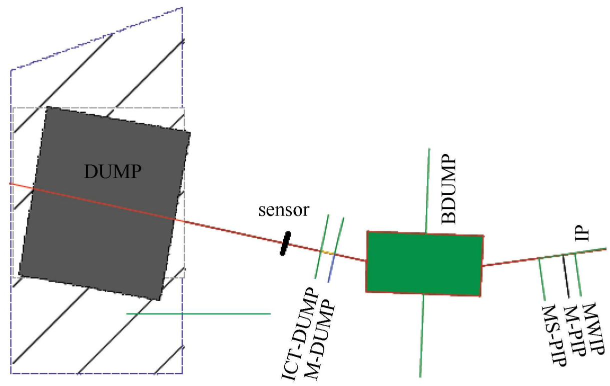

Fig. 5. The ATF2 post-IP region setting.

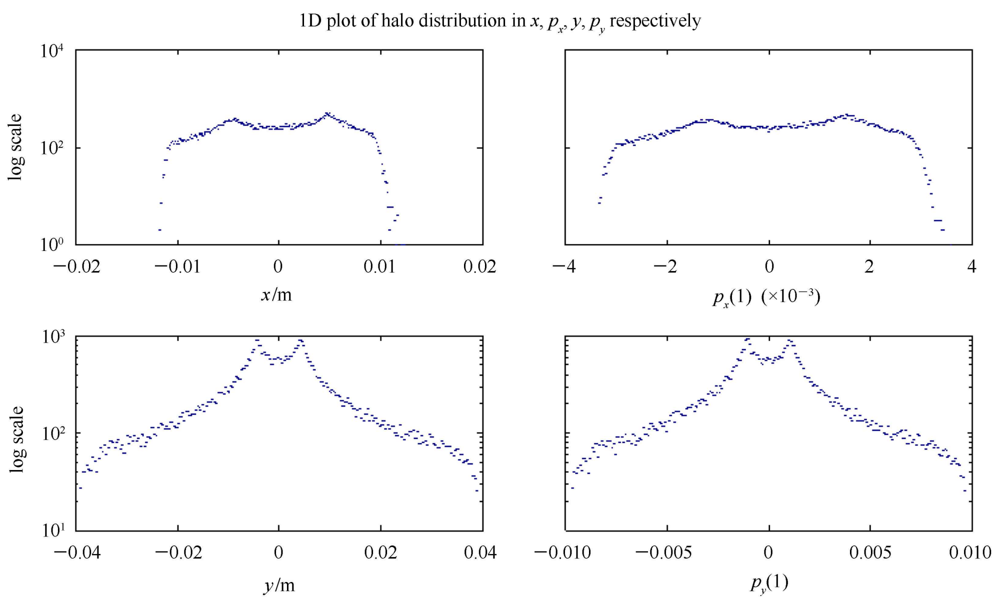

Fig. 6. Halo distribution at MDUMP from 100000 halo particles input with 60σ.

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used in the Shintake monitor. In such interactions, the optical photons are absorbed and re-emitted as gamma photons. These gammas are detected in a gamma detector on the side of the beam dump by the Shintake monitor group, and the beam electrons which are subject to such a Compton interaction lose energy which is communicated to the gamma photon (up to 2.23% of the normal 1.3 GeV) but remain within the beam. After the bend BDUMP, because of their lower energy, they are bent more and can be detected on the edge of the beam halo, which is 1000 times less in number, just a bit beyond the beam halo edge. So the edge of the beam halo should be quite sharp to easily separate the halo electrons and Compton recoil electrons.

As can be seen from Fig. 6, the x edge of halo distribution at MDUMP near the sensor is quite sharp, and it could easily tell the difference between beam halo and Compton recoil electrons.

5 Conclusions and prospects

The realistic apertures along the ATF2 beam line are reported in this paper, and the tightest apertures are the C-band BPMs attached to each quadrupole and sextupole in the final focus line, with only 0.01 m in radius, and may be the source of the background today. A halo generator using the parameterisations from Suehara's past halo measurements, and also some of the input phase space correlations, is used. Halo propagation along the ATF2 beam line with realistic apertures indicates that the halo losses are concentrated on the first two C-band BPMs where β_x and β_y have peaks. Non-linear optics has little effect on the different sigma input halo particles for the ratio of transmitted/initial electron numbers. Halo distribution at the last BPM has quite a sharp edge and will benefit the Compton recoil electrons measurement.

Initial energy spread may be increased in a real system which has non-linear optics influence. The expected halo population is about 10^7, and 100000 halo particles as input are quite less in number. Another uncertainty for the halo is the field quality, which is poorly known for particles very far from the beam axis. There is also the possibility of halo regeneration when particles are intercepted in the C-band BPMs; the present study should continue with more detailed checks using GEANT4.

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