ISTITUTO NAZIONALE DI FISICA NUCLEARE

Laboratori Nazionali di Frascati

INFN-04-2022/LNF
08-06-2022

Beamstrahlung radiation at FCC-ee

Andrea Ciarma[†]
European Laboratory for Particle Physics, CERN
[†]*Email: andrea.ciarma@cern.ch*

Abstract

Beamstrahlung is a dominant effect in high luminosity next-generation lepton colliders. The characterisation of the beamstrahlung radiation produced at the four working points of FCC-ee is presented, together with the tracking of these photons in the MDI region. As the emitted power results to be $\mathcal{O}(100kW)$, the design of a dedicated extraction line is necessary in order to avoid energy deposition and secondary production on the beam pipe material.

Published by
Laboratori Nazionali di Frascati

1 Introduction

In order to achieve high luminosity in next generation colliders it is necessary to squeeze bunches to have extremely small beam sizes at the interaction point (IP). During the bunch crossing, a particle will experience the electromagnetic field provided by the high charge density of the oncoming bunch. Under the effect of this field, the particle will curve its trajectory and radiate: this process (analogous to Synchrotron Radiation) is named Beamstrahlung.

At FCC-ee [1] the horizontal (vertical) beam sizes at the IP are of the order of the μm (nm) and the beamstrahlung has a dominant contribution in the beam lifetime and bunch lengthening. In this work the beamstrahlung radiation emitted at the four working points of FCC-ee is characterised. For this study GuineaPig++ [2] was used to simulate the beam-beam interaction and produce the beamstrahlung radiation.

2 Characterisation of the beamstrahlung radiation at FCC-ee

The beamstrahlung radiation emitted at the four working points of FCC-ee has been simulated using the generator GuineaPig++. For the simulation the beams are assumed gaussian with beam parameters corresponding to the recent 4IP lattice, reported in table 1.

Parameter	Units	Z	WW	ZH	Top
Energy	GeV	45.6	80.0	120.0	182.5
ϵ_x	nm.rad	0.71	2.16	0.64	1.49
ϵ_y	pm.rad	1.42	4.32	1.29	2.98
β_x	m	0.1	0.2	0.3	1
β_y	mm	0.8	1	1	1.6
σ_x^*	μm	8.46	20.78	13.86	38.60
σ_y^*	nm	33.7	65.7	35.9	69.0
σ_{px}^*	μrad	84.26	103.9	46.2	38.6
σ_{py}^*	μm	42.1	65.7	35.9	43.2
σ_z	mm	15.4	8.0	6.0	3.8
N_e	10^{11}	2.43	2.91	2.04	2.37
N_{bunch}	1	10000	880	248	40

Table 1: Beam parameters for the FCC-ee 4IP lattice.

Figure 1 shows the flux and total power of the beamstrahlung radiation at the four beam energies. Because the current is much higher respect to the others, the highest value of power (up to 370kW) is observed at the Z working point. Due to such high values of power emitted, it is important to understand where these photons are emitted and where they will hit some material in the MDI area.

Similarly to the Synchrotron Radiation, also the beamstrahlung photons are emitted in a very narrow cone ($\propto 1/\gamma$) in the direction of the particle which produced them.

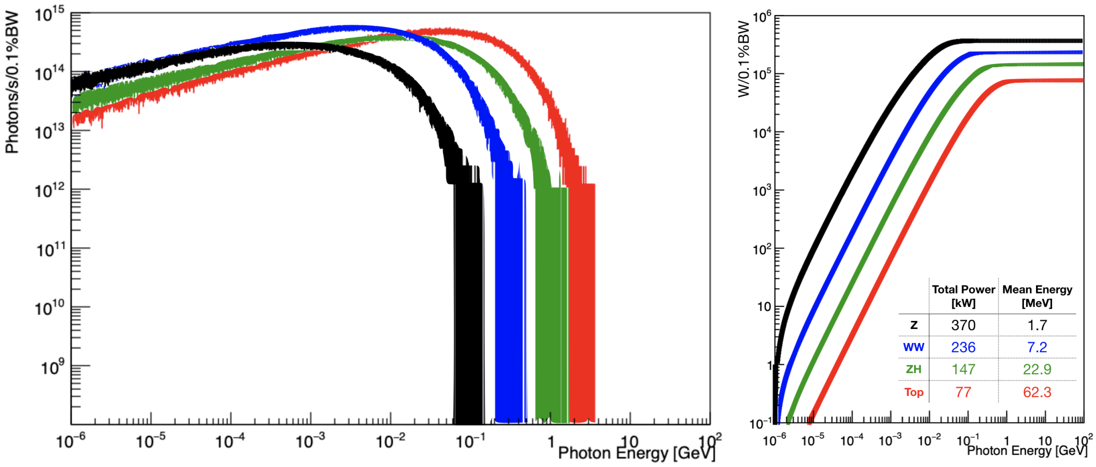


Figure 1: Left: flux of the beamstrahlung photons emitted at the four FCC-ee working points: $45.6\,GeV$ (black), $80.0\,GeV$ (blue) $120.0\,GeV$ (green) and $182.5\,GeV$ (red). Right: cumulative power distribution for the same working points.

Therefore the photon angular spread will be dominated by the contribution of the electron beam divergence, as it can be seen in table 2. As the photon angular spread is $\mathcal{O}(10 \sim 100\,\mu rad)$, the transverse spot size at few hundred meters from the IP will remain of the order of few cm^2.

	$\sigma_{px}(\gamma)\ [\mu rad]$	$\sigma_{py}(\gamma)\ [\mu rad]$	$\sigma_{px}(e^-)\ [\mu rad]$	$\sigma_{py}(e^-)\ [\mu rad]$
Z	91.8	49.2	84.3	42.1
WW	110	73.0	103.4	65.7
ZH	51.7	41.3	46.2	35.9
Top	44.6	50.3	38.6	43.2

Table 2: Divergence of the photon and electron beams.

Due to the 15 mrad crossing angle present in FCC-ee, the beam-beam kick oh the horizontal plane will have a preferred direction. As shown in figure 2, due to the different magnetic rigidity less energetic particles will receive a stronger kick. This means that the center of the radiation spot will be different depending on the working point. As an example, on a transverse plane located at 50m from the IP, the photon distributions for the Z and the Top will less than 2mm apart. Anyway, as mentioned above, the photon spot sizes are of the order of few cm^2 so the irradiated regions will be largely overlapping.

Figure 3 shows the correlation between the photon energy and the horizontal emission angle. This means that the peak of the power angular distribution is slightly shifted. Anyway also in this case the difference is of the order of $\mathcal{O}(10\,\mu rad)$, so even at few hundreds meters from the IP the offset would be of the order of $\mathcal{O}(1mm)$.

The photons produced at the IP have been tracked in the GDML description of the beam pipe in order to see where they will hit. Figure 4 shows that the photons will hit mostly the first downstream dipole (BC1), $\sim 55\,m$ from the IP. Even if the transverse spot

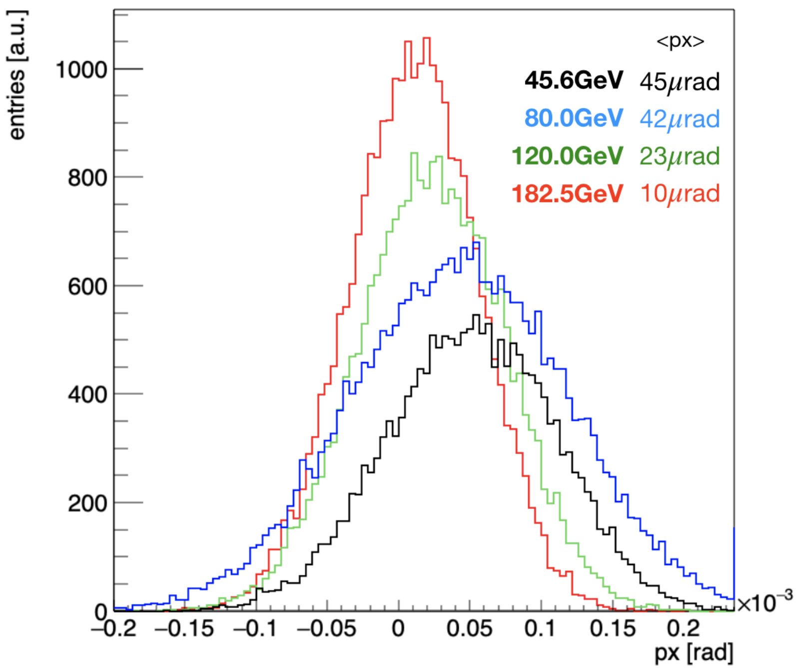


Figure 2: Horizontal angle distribution of the beamstrahlung radiation.

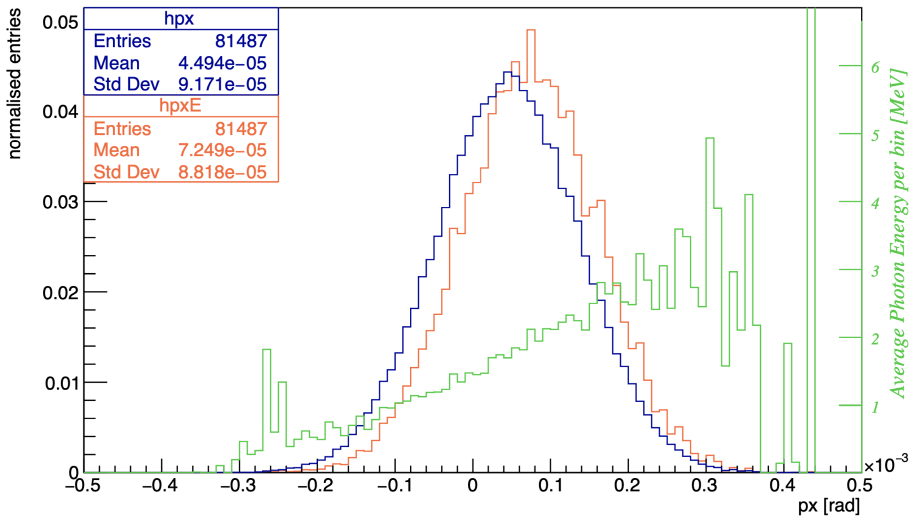


Figure 3: Comparison of the geometrical (blue) and weighted for the energy (red) horizontal angular distribution for the beamstrahlung photons emitted at the Z working point. In (green) the average photon energy per each angular bin.

size at that distance from the IP would be $\mathcal{O}(cm^2)$, the irradiated region is several meters long because the photons imping on the beam pipe with an angle of ~ 1 mrad.

Due to the very high power produced $\mathcal{O}(100kW)$ it is necessary to have a beam dump for the beamstrahlung photons. An extraction line for the photons should be designed in order to avoid any deposition of energy in the beam pipe, to prevent secondary showers or material activation, as shown in figure 5. The design of such line is challenging because of the length of the window (which should be several meters long as seen in

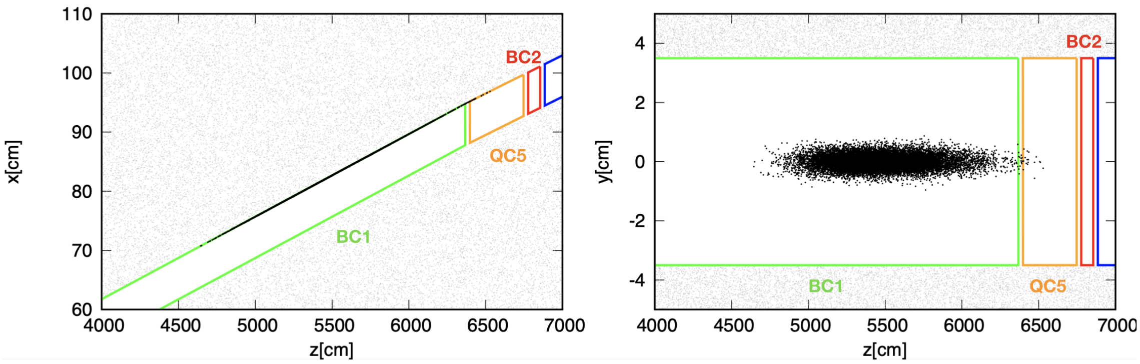


Figure 4: Map of the photons produced at the Z working point hitting on the beam pipe.

figure 4 and extend for several hundreds of meters in order to have the dump itself far from the beam pipe to avoid that its radioactivity could interfere with the machine. A schematic view of the trajectories of the beamstrahlung and electron beam is shown in figure 5). Also the possibility to have an instrumented beam dump to measure properties of the colliding beams at the IP is under investigation.

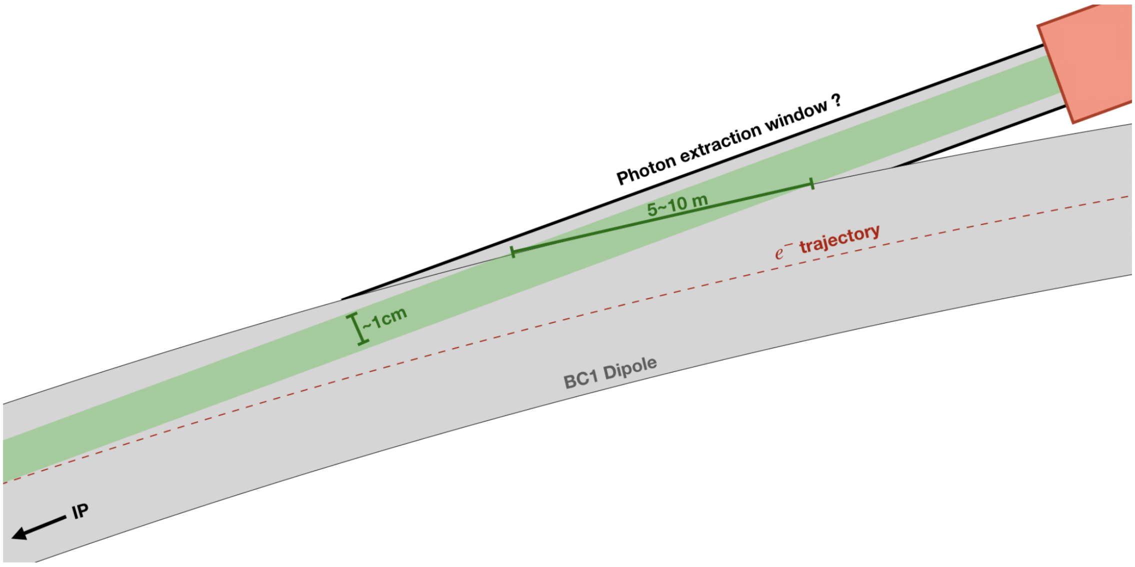
3 Conclusions

The characterisation of the beamstrahlung radiation produced at FCC-ee has been presented. The beamstrahlung photons will hit the beam pipe at the first downstream dipole (~ 55 m from the IP). The emitted power is of the order of $\mathcal{O}(100kW)$ therefore a dedicated beam dump is necessary to avoid secondary production on the beam pipe material.

References

[1] Abada A., Abbrescia M., AbdusSalam S.S. et al. "FCC-ee: The Lepton Collider." Eur. Phys. J. Spec. Top. 228, 261–623 (2019).

[2] D. Schulte, Beam-Beam Simulations with GUINEA-PIG CERN-PS-99-014-LP http://cds.cern.ch/record/382453, Mar, 1999.



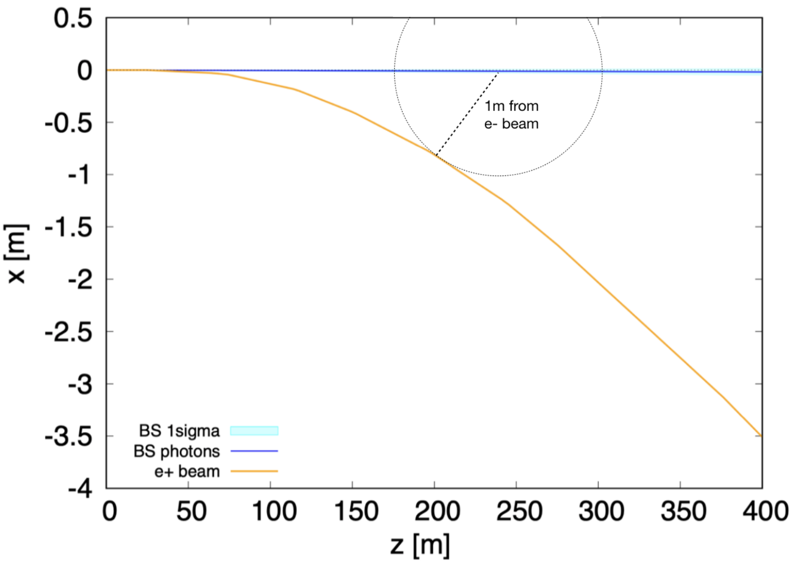


Figure 5: Top: sketch of the extraction line. Bottom: trajectories of the photon and electron beams.