ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPR08

ELECTRON CLOUD STUDIES FOR DAΦNE COLLIDER AND FCCee DAMPING RING

S. Ozdemir*, Ege University, Izmir, Turkiye and Nisantasi University, Istanbul, Turkiye
O. Etisken, Kirikkale University, Kirikkale, Turkiye and LNF-INFN, Frascati, Italy
G. Franzini, C. Milardi, D. Quartullo, A. De Santis, S. Spampinati, M. Zobov
LNF-INFN, Frascati, Italy
R. Ciftci, Ege University, Izmir, Turkiye

Abstract

DAΦNE is a medium energy electron-positron collider operating in the National Laboratory of INFN (National Institute for Nuclear Physics) at Frascati (LNF), Italy. The accelerator complex consists of two rings with an approximate circumference of 97 m. High-intensity electron and positron beams circulate and collide with the center of mass energy of around 1.02 GeV. The FCCee is an ongoing lepton collider project, and its current injector design includes a damping ring for emittance cooling of positron beams. The e-cloud is one the most important collective effects, therefore it can represent a bottleneck for the performances of accelerators storing particles with positive charge. Several undesired effects such as transverse instabilities, beam losses, emittance growth, energy deposition, vacuum degradation may arise due to interaction of the circulating beam with the e-cloud. The aim of the paper is to discuss e-cloud build-up simulations and to compare the simulation results with experimental studies of the instabilities induced by the e-cloud exploiting the opportunity offered by the positron beam in DAΦNE. This paper also includes preliminary e-cloud build-up studies of FCCee Damping Ring (DR).

INTRODUCTION

Electrons generated due to ionization of residual gases, photo-emission by synchrotron radiation during a bunch passage and/or initial electrons in the vacuum pipe can be trapped by the fields of positively charged circulating particles. Electron amplification may occur through the multipacting effect when these electrons get accelerated in the EM field of the beam and hit the chamber walls. The e-cloud build-up saturates when the attractive beam field is compensated by the field of the electrons, at a neutralization density. The e-cloud instability occurs above the density threshold [1–4]. In this study, we present simulation studies concerning e-cloud formation for both the DAΦNE collider, and the FCCee-DR. Besides, tune shift and growth rate measurements have been conducted and compared with simulation results.

* senemozzdemir@gmail.com

Table 1: Beam Parameters of the DAΦNE

Parameter	Value
Energy, E [GeV]	0.51
Circumference, C [m]	97.58
Geo. emit. (h)/(v), ϵ_x [nm·rad]	280/1.4
Bunch length, σ_z [mm]	16
Momentum sprd., σ_δ $(\times10^{-2})$	0.04
Harmonic number, h	120
Mom. compac., α_c $(\times10^{-2})$	1.86
Tune (h)/(v), Q_h/Q_v	5.087/5.198
Energy loss/turn, U_0 [MeV]	0.0097
Chamber radius (wiggler) (h)/(v), b [mm]	60/10
Bunch pop., e^-/e^+, N_b $(\times10^{10})$	2.75/1.85
Bunch spacing, ΔT_b [ns]	2.71
Number of bunches, n_b	110

Table 2: Measured Tune Shift and Simulated e⁻ Density for Different Beam Currents for 105 Bunches Configuration

Beam current	Measured tune shift	e^- density
800 mA	7.0×10^{-3}	8.8×10^{13} m^{-3}
750 mA	6.3×10^{-3}	8.0×10^{13} m^{-3}
600 mA	4.8×10^{-3}	6.0×10^{13} m^{-3}
400 mA	3.3×10^{-3}	3.5×10^{13} m^{-3}

E-CLOUD STUDIES FOR DAΦNE

Beam Parameters

The e-cloud formation depends on many parameters such as: external magnetic fields, geometry, chamber surface, bunch spacing, bunch intensity, bunch length, bunch number, and beam sizes. In addition, another key parameter to be taken carefully into account is the Secondary Electron Yield (SEY), it is defined as the ratio between the emitted and impacted electron current as a function of the energy of the impacting electrons. The SEY curves for various δ_{max} (maximum of the SEY curve), and E_{max} (energy corresponding to the maximum SEY) are shown in Fig. 1. Alongside the beam parameters summarized in Table 1, the 'ECLOUD' model in PyECLOUD reference manual [5] is used for SEY curve as described in [6], and δ_{max} is chosen 1.9 (and E_{max}=332 eV) for Al surface in the simulations [7, 8].

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPR08

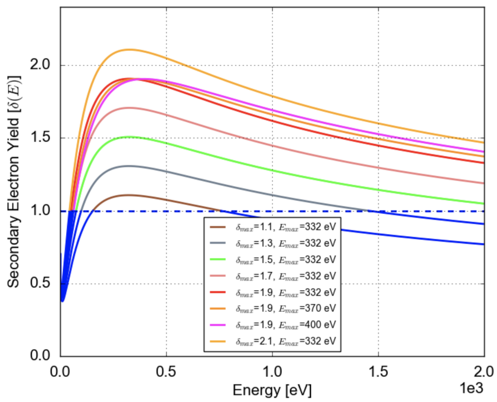

Figure 1: SEY curves for various δ_{max} and E_{max}.

Measurements and Build-up Simulations

Analysis of the signals acquired by the bunch-by-bunch transverse feedback system allows measuring the fractional tunes of each bunch along the train [8]. Horizontal tune shift through the bunch train has been measured for 105 filled bunches, and is shown in Fig. 2 (top). Even though the feedback system was on during the measurements it was impossible to store more than 800 mA in this configuration without losing the beam due to the instability. Typically, the instability threshold is considerably higher when the beams are in collisions. The measured tune shift between the first and the last bunches for 800 mA beam current is of the order of $7{\times}10^{-3}$. Besides, e-cloud build-up simulation has been performed by using PyECLOUD [5], as also shown in Fig. 2 (bottom) in the wiggler magnet. The main contribution to the e-cloud formation in DAΦNE comes from the wiggler magnets. The e-cloud density increases at the beginning of the bunch train and reaches saturation after $0.88{\times}10^{14}$ m^{-3}. This is compatible with our estimation based on measured tune shift, taking into account that only 8% of the machine is filled with wiggler magnets. Similar measurements and simulation studies have been conducted for lower beam currents for the same bunch configuration. The e^- density evaluated by simulations decreases for lower beam currents in accordance with the measured tune shift reduction reported in Table 2. Figure 3 shows the measured tune shift (top) and the electron cloud build-up simulations (bottom) for another filling pattern which consists of 6 filled and 6 empty buckets, totally 60 bunches. For the considered beam current of 290 mA the tune shift is lower for this pattern which is around $0.5{\times}10^{-3}$, and the e$^-$ density result confirms this reduction with lower value around $1.5{\times}10^{13}$ m^{-3} with respect to the 105 bunch case.

We have taken another useful measurement with the feedback system to study the horizontal instability of the e^+ beam

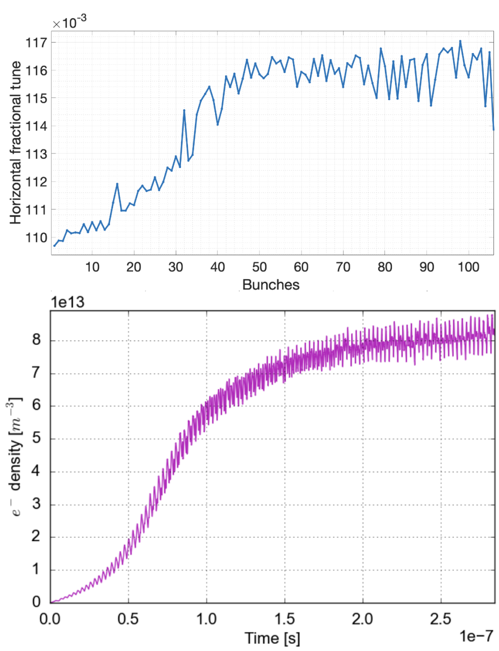

Figure 2: Horizontal tune shift measurement for 105 filled bunches (800 mA) (top) and e-cloud build-up simulation by PyECLOUD (bottom).

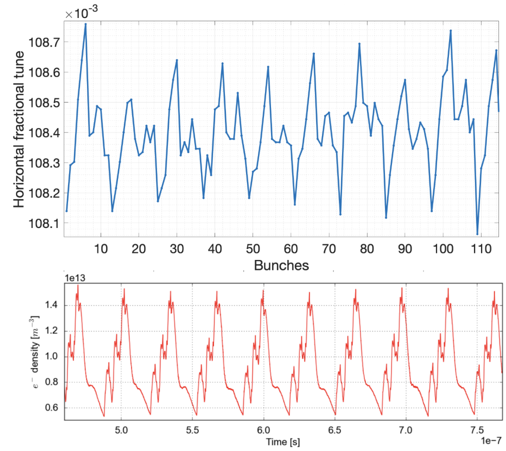

Figure 3: Horizontal tune shift measurement for 60 bunches (each train has 6 filled 6 empty buckets) which correspond to 290 mA beam current (top) and e-cloud build-up simulation by PyECLOUD (bottom).

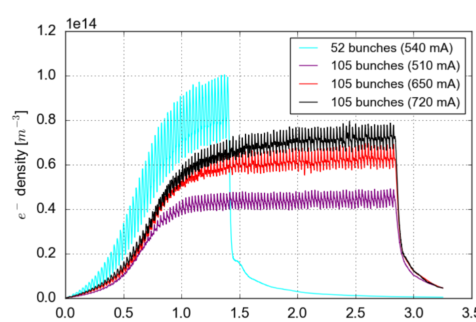

Figure 4: E-cloud formation for 52 bunches at 540 mA beam current (blue), 105 bunches for 510 mA (purple), 650 mA (red) and 720 mA (black) beam currents.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPR08

Table 3: Growth rate and simulated e⁻density for different filling pattern and beam currents.

Bunch no	Growth rate	e^- density
105 bunches [720 mA]	44 ms^{-1}	0.8×10^{14} m^{-3}
105 bunches [650 mA]	22 ms^{-1}	0.7×10^{14} m^{-3}
105 bunches [510 mA]	6 ms^{-1}	0.5×10^{14} m^{-3}
52 bunches [540 mA]	18 ms^{-1}	1.0×10^{14} m^{-3}

due to e-cloud: the instability growth rate. For this measurement, the e^+ beam instability was artfully induced by switching off the horizontal feedback for a given time in the scale of ms in non-collision operation mode. The bunch-position signals were used as input for the modal analysis, which provided the growth rates of the different modes. In addition, we have performed e-cloud build-up formation simulation for the same bunch pattern and beam currents. Several growth rates and simulated e-cloud densities are summarized in Table 3. In this regard, the modal analysis revealed a growth rate of 22 ms^{-1} for the mode -1 for bunch filling pattern consisting of 105 bunches at a beam current of 650 mA, which is in good agreement with the growth rate of 18 ms^{-1} determined by a similar mode analysis in 2008 [9, 10]. The simulated built-up e-cloud density is decreasing with lower beam current as expected for 105 bunches. In addition, the growth rate for 52 consecutive bunches is 18 ms^{-1} at 540 mA, which is higher than in the case of 105 bunches at similar beam current. The e^- density in Fig. 4 confirms that 52 bunch consecutive filling pattern is determining higher e-cloud density. This study will be analyzed and supported with more measurements.

E-CLOUD STUDIES FOR FCCee DR

The FCC-ee injector complex layout consists of an electron source, three LINACs (for e^-, e^+ and common for both e^+/e^-) up to 6 GeV, a positron target, energy compressor, bunch compressor and a DR at 1.54 GeV [11–15]. Analytical estimates related to e-cloud have been performed for the DR; thus, the neutralization and threshold density were calculated close to each other which is around 0.4×10^{13} m^{-3}. In this regard, the build-up and instability simulations should be checked for the equilibrium state with detailed simulations. The first step is to simulate the e-cloud formation and then instability simulations should be performed by using the e-density. Build-up study has been started for the DR design at 1.54 GeV in the dipole magnet. Parameters used in the simulation are the following: The primary e^- rate is 0.0075, maximum SEY is 1.9, energy at maximum SEY is 332 eV, external magnetic field is 0.66 T, bunch length is 2 mm, chamber radius are 25 mm/9 mm (h/v), total bunch number is 18 with 25 ns bunch spacing. The e-cloud formation is shown in Fig. 5. Thus, e^-density is building up to 0.6×10^{13}. This density is higher than analytically estimated threshold and it requires further investigation in the following process since it may indicate instability.

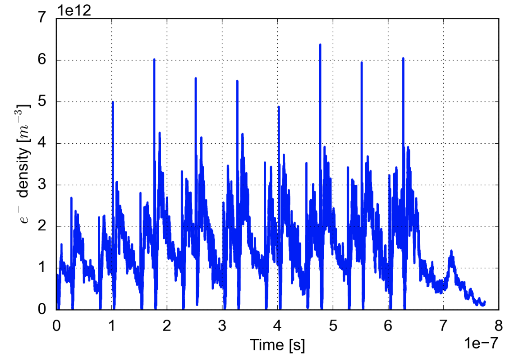

Figure 5: E-cloud build up formation for the DR at 1.54 GeV.

In parallel to existing DR design, a new DR layout study has been started after FCC midterm review report [11, 16]. Higher energy damping ring option at 2.86 GeV has been considered, which could lead to a remarkable simplification in the general pre-injector layout maintaining or even reducing the LINACs total accelerating lenght [15, 17, 18]. Preliminary optics studies shows that design parameters meet the prerequisite of the pre-injector complex with a DR working at the energy of 2.86 GeV as having larger circumference of about 380 m [16, 19, 20]. In addition, another option by using DQ combined magnets are also under study with shorter circumference (around 320 m). Besides, using revised CLIC-PDR design is also under consideration for FCCee-DR. Thus, in the following process, the build-up studies will be re-performed and detailed for the new DR considerations.

CONCLUSION

E-cloud studies highlighting significant impact on accelerator performances, for both the DAΦNE collider and the FCCee-DR have been presented. We have compared simulated electron densities with experimental results such as tune shift and growth rate measurements for the DAΦNE e^+ ring. The indications provided by the numerical simulations are in accordance with the experimental measurements. This makes us more confident in the results of the e-cloud effect simulations for future lepton colliders and storage rings. In particular, we have performed preliminary simulations for FCCee DR, which comply with the estimated value based on analytical calculation. This electron density may indicate instability, and require further investigation in the following process. Besides, the build-up simulation will need to be re-performed for higher energy DR option (2.86 GeV). These findings contribute to a better understanding of e-cloud behavior, guiding future design, and operational strategies to improve stability, and performances in particle accelerators.

ACKNOWLEDGEMENTS

We would like to thank Lotta Mether, Konstantinos Paraschou, Giovanni Iadarola, Geofrey Humberto Israel Maury Cuna, Luca Sabato for their help about PyECLOUD code.

ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-WEPR08

REFERENCES

[1] F. Zimmermann, "Two-Stream Effects in Present and Future Accelerators", in *Proc. EPAC'02*, Paris, France, Jun. 2002, THZGB001, pp. 25–29.

[2] G. Rumolo and G. Iadarola. "Electron Clouds", in *Proc. of the CAS-CERN Accelerator School: Intensity Limitations in Particle Beams*, CERN, Geneva, 2017, vol. 3, CERN-2017-006-SP. doi:10.23730/CYRSP-2017-003.411

[3] O. Etisken, F. Antoniou, A. De Santis, C. Milardi, and F. Zimmermann, "Collective Effects Estimates for the Damping Ring Design of the FCC-ee", in *Proc. IPAC'22*, Bangkok, Thailand, Jun. 2022, pp. 2435–2438. doi:10.18429/JACoW-IPAC2022-THPOST003

[4] O. Etisken, F. Antoniou, K. Oide, Y. Papaphilippou, F. Zimmermann, and A.K. Çiftçi, "Estimates of Collective Effects for the FCC-e e Pre-Booster Ring", in *Proc. of IPAC'21*, Campinas, SP, Brazil, May 2021, MOPAB032. doi:10.18429/JACoW-IPAC2021-MOPAB032

[5] *PyECLOUD Reference Manual*, G. Iadarola, E. Belli, P. Dijkstal, L. Mether, A. Romano, G. Rumolo, and E. Wulff, CERN, Geneva, Switzerland. https://github.com/PyCOMPLETE/PyECLOUD

[6] G. Iadarola. "Electron Cloud Studies for CERN Particle Accelerators and Simulation Code Development", PhD Thesis,Universitá degli Studi di Napoli Federico II, Naples, Italy, CERN-THESIS-2014-047, 2014.

[7] T. Demma, R. Cimino, S. Guiducci, C. Vaccarezza, and M. Zobov, "Electron Cloud Simulations for DAΦNE", in *Proc. of EPAC08*, Genoa, Italy, 2008, TUPP031.

[8] Alesini, D. and Drago, A. and Gallo, A. and Guiducci, S. and Milardi, C. and Stella, A. and Zobov, M. and De Santis, S. and Demma, T. and Raimondi, P., "Operation with Electron-Cloud-Clearing Electrodes", *Phys. Rev. Lett.*, vol. 110, p. 124801, March, 2013. doi:10.1103/PhysRevLett.110.124801

[9] A. Drago, D. Teytelman, and M. Zobov, "Recent Observations on a Horizontal Instability in the DAFNE Positron Ring", in *Proc. PAC'05*, Knoxville, TN, USA, May 2005, paper MPPP024, pp. 1841–1843.

[10] C. Milardi *et. al.*, "DAΦNE Operation Strategy for the Observation of the Kaonic Deuterium", presented at IPAC'24, Nashville, Tennessee, USA, 2024, WEPR17, this conference.

[11] A. Abada *et al.*, "FCC-ee: The Lepton Collider", *Eur. Phys. J. Spec. Top.*, 228, 261–623, 2019. doi:10.1140/epjst/e2019-900045-4

[12] K. Oide *et al.* "Design of beam optics for the future circular collider e^+e^- rings", *Phys. Rev. Accel. Beams*, 19, 111005, 2016. doi:10.1103/PhysRevAccelBeams.19.111005

[13] P. Craievich *et al.*, "The FCCee Pre-Injector Complex", in *Proc. IPAC'22*, Bangkok, Thailand, Jun. 2022, pp. 2007–2010. doi:10.18429/JACoW-IPAC2022-WEPOPT063

[14] C. Milardi *et al.* "FCCee injector complex: damping ring and transfer lines of FCCe$^-$e$^+$ injector complex (WP4)", in *Proc. of IPAC2023*, Venice, Italy, May 2023, MOPA112. doi:10.18429/JACoW-IPAC-23-MOPA112

[15] S. Spampinati, A. De Santis, O. Etisken "Emittance and energy distribution reduction in the positron injector of FCC-e+e-", presented at IPAC'24, Nashville, Tennessee, USA, WEPR17, this conference.

[16] O. Etisken *et al.*, "New consideration for the damping ring design of the FCC e+e- injector complex", *in Proc. of IPAC'23*, Venice, Italy, May 2023, MOPL175. doi:10.18429/JACoW-IPAC2023-MOPL175

[17] S. Bettoni *et al.*, "FCC-ee Injector Study and the P3 Project at PSI", PSI, 2023.

[18] S. Bettoni *et al.*, "FCC-ee Injector Study and the P3 Project at PSI", PSI, 2022.

[19] P. Craievich *et al.*, "The FCCee pre-injector complex", in *Proc. IPAC'22*, Bangkok, Thailand, Jun. 2022, pp. 2007–2010. doi:10.18429/JACoW-IPAC2022-WEPOPT063

[20] "FCC Feasibility Study Mid-Term Review: Updated cost assessment for the FCC civil engineering, infrastructure and FCC-ee collider", CERN/3796/RA, February 2024. https://cds.cern.ch/record/2888568