PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Leonardo Sito

Cycle: XXXVIII

Training and Research Activities Report

Year: First

Tutor: prof. Giovanni Breglio

Co-Tutor: prof. Francesco Fienga

Date: December 4, 2023

1. Information:

- **PhD student: Leonardo Sito**
- **DR number: 996982**
- **Date of birth: 06/06/1997**
- **Master Science degree: Electronics Engineering** **University: Federico II**
- **Doctoral Cycle: XXXVIII**
- **Scholarship type: *Funding company: CERN***
- **Tutor: prof. Giovanni Breglio**
- **Co-tutor: prof. Francesco Fienga**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
Title: 5G Academy – Open Digital Framework Lecturer: Alberto Curcio, Manager&Head of TMT Portfolio, Valeria Crimaldi, Analyst Consultant, Capgemini Invent, Italy	Seminar	3	0.6	17/01	5G Academy	Y
Title: Multi-Robot Control of Heterogeneous Herds Lecturer: Prof. Eduardo Montijano, Associate Professor, Department of Informatics and Systems Engineering, Universidad de Zaragoza, Spain	Seminar	1	0.2	16/02	Scuola Superiore Meridionale	Y
Study on the CTPPS Beam-Coupling Impedance and Dissipated Power. Study from literature on material characterization. Preparation of the conference paper on	Research		9.2			

BBLRC Demonstrator for IPAC23. Laboratory activity on measurements of conductivity and permeability of laminated Silicon Steel.						
Title: Wakefields and Collective Beam Instabilities Lecturers: Gennady Stupakov (SLAC), Ryan Lindberg (Argonne National Lab) Boris Podobedov (Brookhaven National Lab).	Doctoral School	83	5	23/01 to 03/02	USPAS and Northern Illinois University	Y
Title: 5G Academy – Il cloud e gli Hyperscalers / High Performance Computing Lecturer: Giovanni Vendramel, Head of Cloud Transformation | Principal consultant Capgemini Invent and Klodiana Goga, Senior Consultant Capgemini Invent Organizer 5G Academy, Capgemini	Seminar	3	0.6	28/02	5G Academy	Y
Title: 5G Academy – Sustainable Strategy Lecturer: Anna Bartnik, Consultant | Capgemini Invent, Andrea Spitaleri, Analyst Consultant | Capgemini Invent	Seminar	3	0.6	03/03	5G Academy	Y
Title: The Laser-hybrid Accelerator for Radiobiological Applications	Seminar	1	0.2	30/03	CERN ATS	Y

Lecturer: Professor Kenneth Richard Long – Imperial College (GB)						
Title: High Power Targetry R&D Program with the RaDIATE Collaboration and target perspectives in framework of Snowmass Lecturer: Dr. Frederique Pellemoine, Fermi National Accelerator Laboratory, Batavia, USA	Seminar	1	0.2	30/03	CERN ABP Forum	Y
Title: Beam-Beam Bremsstrahlung Beam-Size Effects and FCC-ee Beam Lifetime Lecturer: Krzysztof Piotrzkowski (AGH UST Krakow)	Seminar	2	0.4	31/03	CERN ABP Forum	Y
Title: Learning gene association networks using single-cell RNA-seq data: a graphical model approach. Lecturer: Prof. Davide Risso, University of Padua, Padua, Italy	Seminar	1	0.2	31/03	DIETI	Y
Title: Accurate and Efficient Numerical Modeling Methods for Superconducting Circuit Quantum Information Processing Devices Lecturer: Prof. Thomas E. Roth, Purdue University, Elmore Family School of Electrical and Computer Engineering, USA	Seminar	1	0.2	03/04	DIETI	Y

Title: Enhancing qubit readout with Bayesian Learning Lecturer: Dr. Nicola Lo Gullo (University of Calabria)	Seminar	1	0.2	05/04	QST Seminars, Department of Physics, Federico II	Y
Study on metamaterials and production choices. Laboratory activity measurement of metamaterials resonant frequency. Preparation of conference paper and poster “Beam-Beam long range Mechanical demonstrator” for IPAC23. Revision of the paper “F.Fienga et al., Direct measurement of beam induced heating on accelerator pipes with fiber optic sensors: numerical analysis validation” submitted at IEEE TIM.	Research		2.4			
Title: Statistical data analysis for science and engineering research Lecturer: Prof. Roberto Pietrantuono, DIETI	Courses		4	06-08-10-13-15-16/02 exam on 09/05	DIETI	Y
Title: Spring School on Transferable Skills Lecturers: Prof. Pasquale Maffia and Prof. Valeria Costantino, University of Naples Federico II	Doctoral School		2	24-25/05	UNINA. Department of Pharamacy	Y
Title: Surface Electromagnetics for	Doctoral School		4	15/05 to 19/05	University of Trento and	Y

Wireless Communications and Sensing Lecturers: Prof. Giacomo Oliveri, Dr. Salas-Sanchez Aaron A., Prof Marco Salucci					ELEDIA research center	
Title: Nanoneuro: the power of nanoscience to explore the frontiers of neuroscience" Lecturer: Dr. Aitzol Garcia-Etxarri - Ikerbasque researcher - Donostia International Physics Center, Spain	Seminar	1	0.2	03/05	DIETI	Y
Title: Nonlinear surface impedance of superconductors in high magnetic fields Lecturer: Prof. Ruggero Vaglio, University of Naples Federico II and CNR-SPIN, Genova, Italy	Seminar	2	0.4	23/05	CERN	Y
Title: Symbiotic Control of Wearable Soft Suits for human motion assistance and augmentation Lecturer: Prof. Lorenzo Masia, Chair in "Biorobotics and Medical Technology", Institut für Technische Informatik (ZITI) Heidelberg University, Germany	Seminar	2	0.4	26/05	Prof. Fanny Ficuciello	Y
Preparation of conference paper and poster "Beam-Beam long range mechanical	Research		1			

demonstrator" for IPAC23. Preparation of conference paper for SIE-2023 meeting. Plots preparation for conference paper for OFS28. Studies on the SPS Wire Scanner breakage due to impedance heat loads.						
Title: Academic Entrepreneurship Lecturer: prof. Pierluigi Rippa, Silvia Cosimato, Nadia Di Paola - DIE Unina	Courses		4	29-31/05 and 05-15-20-22/06, exam on 17/07	DIETI	Y
Title: Optimization of the High-Brightness Beam Performance of the CERN PSB with H- Injection Lecturer: Dr. Tirsi Prebibaj, CERN	Seminar	1	0.2	10/07	CERN	Y
Study on SPS Wire Scanner beam-coupling impedance mitigation solutions. Study on LHC RF Modules non-conformities and heating due to beam-coupling impedance. Study on longitudinal and transverse impedance measurements with bead-pull methods. Preparation of the conference paper for	Research		5.8			

SIE2023: "Validation of FBG sensors for thermal monitoring of the Central Beam Pipe of CMS". Preparation of the conference paper for OFS28: "Improved Thermal Monitoring in Particle Accelerators Using FBGS: First Insights from the IPIPE Project in LHC Run 3".						
Title: The design of the ENUBET beamline Lecturer: Elisabetta Giulia Parozzi (CERN)	Seminar	1	0.2	15/09	CERN	Y
Title: Collective Effects in Lepton Circular Colliders and Synchrotron Light Sources Lecturer: Prof. Mikhail Zobov	Seminar	1	0.2	09/10	High Brightness Hadron Beams Workshop	Y
Title: Predominantly electric "E&m" storage ring with nuclear spin control capability Lecturer: Prof. Richard Talman	Seminar	1	0.2	12/10	High Brightness Hadron Beams Workshop	Y
Measurements of the beam coupling impedance of the LHC RF Modules. Study of modes in corrugated waveguides and waveguides with anisotropic impedance boundary condition. Longitudinal and Transverse impedance	Research		9.4			

model of CTPPS detectors (V4). Preparation of the conference paper and poster for HB2023: "A Python Package to Compute Beam-Induced Heating in Particle Accelerators and applications".						
Title: Artificial Intelligence and Natural Language Processing Lecturer: Prof. Francesco Cutugno, dr. Dr. Maria Di Maro, prof. Antonio Orilia, prof. Vincenzo Norman Vitale	Courses		3	25-27-29/09 and 02-04/10 exam on 27/11	DIETI	Y
Title: Diffusive models and chaos indicators for non-linear betatron Motion Lecturer: Carlo Emilio Montanari, PhD	Seminar	1	0.2	17/11	CERN ABP Seminars	Y
Title: Ensuring Electronic Reliability Against CERN's Radiation Environment Lecturer: Salvatore Danzeca, PhD	Seminar	1	0.4	01/12	DIETI	Y

1) Courses, Seminar, Doctoral School, Research, Tutorship
2) Choose: Y or N

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1		**0.8**	**9.2**		**10**
Bimonth 2	**5**	**2.6**	**2.4**		**10**
Bimonth 3	**10**	**1**	**1**		**12**
Bimonth 4	**4**	**0.2**	**5.8**		**10**
Bimonth 5		**0.6**	**9.4**		**10**
Bimonth 6	**3**	**0.6**	**6.4**		**10**
Total	**22**	**5.8**	**34.2**		**62**

Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

The main topic of my PhD research is an investigation on the use of metamaterials for mitigating the beam-coupling impedance in accelerator components.

More specifically, in a particle accelerator, bunches of charged particles travel inside several different vacuum chambers (these can be just simple metallic pipes or more complex structures). In particle accelerators like the LHC at CERN one has to deal with high energies and high intensities (i.e. high number of accelerated particles). In this scenario, the electromagnetic field carried by the bunch of particles interacts in a non-negligible way with the metallic structure in which the particles are contained. In the field of particle physics, this interaction is described considering a complex vector quantity that is commonly referred to as the beam-coupling impedance. The beam-coupling impedance is related to the Fourier transform of the fields excited in a particular structure by the passage of the particle bunch. It is a fundamental concept that can lead to several issues (excessive heating deposited in the structure, triggering of beam instabilities) if not accounted for correctly.

The main idea behind the PhD project would be to use electromagnetic metamaterials for manipulating the beam-coupling impedance. More in detail, metamaterials are artificial periodic structures with characteristic dimensions much smaller than the operating wavelength. Since the dimensions of each small piece of the structure (usually called a unit cell) are way smaller than the wavelength, one can assume that they can be treated as effectively homogeneous materials. For this reason, they are characterized by the electromagnetic parameters (index of refraction, impedance, permeability and permittivity) that are typically used for common materials.
The interesting thing about metamaterials is that they can be engineered to present unusual properties not readily available in nature.

In the literature, there are two possible approaches for using metamaterials in beam-coupling impedance control:

1) *Use of metamaterials as absorbers of incident EM waves. It was shown that when slabs of metamaterials are placed in strategic positions inside the vacuum chambers the resonances of the structure can be greatly attenuated.*
2) *Use of metamaterials for reducing the effective resistivity of a metallic chamber by tapering the metallic walls with a metamaterial layer.*

These two approaches represent only proof of principle studies and there are possibilities of bringing the studies further.

In this first year, I have dedicated a considerable amount of time to background studies and literature research. More in detail:

- *I have studied the beam-coupling impedance concept and its implications. More specifically the impact that the beam-coupling impedance has on the particle beam motion (i.e. the instabilities that it can trigger) and the heating effects that can be caused by it.*
  The USPAS course "Wakefields and Collective Beam Instabilities" was devoted to this purpose.
- *I have studied the basics of metamaterials and metasurfaces. During this stage, I focused on:*
  - *The definition of common material electromagnetic properties (permittivity and permeability).*
  - *The definition of electromagnetic metamaterials and an in-depth study of the most common MNG metamaterial implementation (the split ring resonator). This was done following an analytical approach.*
  - *Literature study on material and metamaterials parameters extraction (usually referred to as parameter retrieval) approaches both in measurement and in simulation. This is done assuming that the material can be considered isotropic.*
  - *Use of electromagnetic full-wave simulation tools (CST and HFSS) for designing metamaterial unit cells. More specifically, the course "Surface Electromagnetics for Wireless Communications and Sensing" has been greatly helpful in understanding how to set up the simulations (in HFSS) for periodic structure and extract parameters (refractive index and surface impedance).*
  - *For bulk metamaterials, I benchmarked the simulation techniques and parameter retrieval with literature resources.*
  - *Literature study on production techniques for metamaterials. Moreover, needing to insert the metamaterial slabs in ultra-high vacuum environments, there was a first research of vacuum-compatible substrates.*

In this first year, I focused on further studying the approach of using metamaterials for reducing the effective resistivity of the walls of a metallic chamber.

The basic idea is that, by tapering the metallic walls of a circular (or rectangular) waveguide with a single-negative metamaterial layer (i.e. either permeability or permittivity has negative values), it would be possible to reduce the effective surface resistivity of the chamber.
More specifically, in a recent study presented in a paper, a circular waveguide gets tapered with a certain thickness of a layer of single negative material. For the analytical calculations, the layer is assumed to be lossless and isotropic (both properties are not true for real metamaterials). Under the appropriate assumptions, it is possible to transport (with a transmission line approach) the surface impedance of the outer layer (the metal) through the metamaterial layer and obtain the effective impedance of the chamber. It is analytically shown that, after a certain frequency, the effective surface impedance reduces drastically.
In this paper, to give an experimental validation of this phenomenon a reflection experiment is presented: a rectangular waveguide is closed at one extremity to form a resonant cavity. The resonant modes are measured with the empty cavity and when the two vertical walls present a metamaterial layer tapering. The result is that some of the resonant modes show an enhanced resonant peak. This could be attributed to a lower effective surface impedance of the walls, hence, to lower losses.

I am trying to recreate what was done in this literature resource and possibly extend the experimental part to a transmission experiment. To move in this direction I am in the process of engineering a metamaterial unit cell respecting the conditions expressed in the paper.

Finally, I was involved in several other activities:

- *I developed a Python package for computing the power deposited by the particle beam in an accelerator component. The name of the package is BIHC (https://github.com/ImpedanCEI/BIHC)*
- *I have studied and applied two methods (commonly used in literature) for measuring the surface conductivity of thin (3 to 6 um) coatings of metal. The first one employs a TM011 cavity and a calibration strategy to retrieve the conductivity of a sample. The second one is an Eddy current method. The latter activity involved the supervision of an intern at CERN.*
- *I have participated in mechanical and thermal tests of the wire compensator (Beam-Beam Long Range Compensator, BBLRC) for the upgrade of LHC.*
- *I have participated in a task force to determine the breakage cause of the Beam Wire Scanner in the SPS machine. More specifically it involved power and thermal studies of the device in the breakage scenario and several mitigation scenarios.*
- *I have participated in a task force to determine the breakage cause of the RF modules in the LHC machine. More specifically it involved power and thermal studies of the device in the breakage scenario.*
- *I have collaborated in developing and testing a new method of measuring the transverse beam-coupling impedance of a device using a metallic bead to perturb the device itself (Bead-pull method). The activity involved the co-supervision of a CERN summer student.*
- *Modelling and simulations of impedance and power dissipation of the CMS Totem Proton Precision Spectrometer in their current versions (V4 and vertical box) and its possible future design (V5.3).*

4. Research products:

Journal papers:

- *Title: "Experimental tests of a full analog fiber optic monitoring system suitable for safety application at CERN"*
  - *Authors: V.R. Marrazzo, F. Fienga, L. Sito, N. Beni, Z. Szillasi, M. Riccio, S. Buontempo, A. Irace, and G. Breglio*
  - *Journal: IEEE Transactions on Instrumentation and Measurement*
  - *Acronym: IEEE Trans Instrum Meas*
  - *Status: Published in 2023.*

- *Title: "Direct Measurement of Beam-Induced Heating on Accelerator Pipes With Fiber Optic Sensors: Numerical Analysis Validation"*
  - *Authors: F. Fienga, V.R. Marrazzo, L. Sito, F. Giordano, N. Beni, Z. Szillasi, A. Irace, W. Zeuner, B. Salvant, S. Buontempo, and G. Breglio*
  - *Journal: IEEE Transactions on Instrumentation and Measurement*
  - *Acronym: IEEE Trans Instrum Meas*
  - *Status: Published in 2023.*

Conference papers:

- *Title: "Beam-Beam Long Range Compensator Mechanical Demonstrator"*
  - *Authors: L. Sito, C. Accettura, A. Bertarelli, F. Carra, M. Garlaschè, L. Gentini, J. Guardia Valenzuela, M. Guinchard, S. Hoell, F. Motschmann, Y. Papaphilippou, A. Rossi, O. Sacristan de Frutos, G. Sterbini,*
  - *Conference: Internation Particle Accelerator Conference, Venice, Italy*
  - *Acronym: IPAC'23*
  - *Status: Published, 2023*

- *Title: "A Python Package to Compute Beam-Induced Heating in Particle Accelerators and Applications"*
  - *Authors: L. Sito, E. de la Fuente, F. Giordano, G. Rumolo, B. Salvant, and C. Zannini*
  - *Conference: High Brightness Hadron Beams Workshop, 2023, Geneva, Switzerland.*
  - *Acronym: HB2023*
  - *Status: Published, 2023. To be published in IoP*

- *Title: "Validation of FBG sensors for thermal monitoring of the Central Beam Pipe of CMS"*
  - *Authors: L. Sito, F. Fienga, V. R. Marrazzo, N. Beni, S. Buontempo, F. Carra, F. Giordano, A. Irace, B. Salvant, Z. Szillasi, and G. Breglio*
  - *Conference: Società Italiana di Elettronica Annual Meeting, Noto, Italy*
  - *Acronym: SIE2023*
  - *Status: Accepted for publication, 2023*

- *Title: "Improved Thermal Monitoring in Particle Accelerators Using FBGs: First Insights from the iPipe Project in LHC Run 3"*
  - *Authors: F. Fienga, V.R. Marrazzo, L. Sito, N. Beni, Z. Szillasi, A. Irace, W. Zeuner, B. Salvant, S. Buontempo, and G. Breglio*
  - *Conference: 28th International Conference on Optical Fiber Sensors, Hamamatsu, Japan*
  - *Acronym: OFS-28*
  - *Status: Accepted for publication, 2023*

5. Conferences and seminars attended

- *Conference/Workshop name: Joint Accelerator Performance Workshop 2023, Montreaux, Switzerland.*
  - *Acronym: JAP'23*
  - *Dates: 5-7 December 2023*

- *Conference/Workshop name: Proton Precision Spectrometer 2nd Upgrade Workshop 2023, Geneva, Switzerland.*
  - *Acronym: PPS2*
  - *Dates: 23-24 October 2023*
  - *Presentation: "Beam-Coupling Impedance Update of CTPPS"*

- *Conference/Workshop name: High Brightness Hadron Beams Workshop, 2023, Geneva, Switzerland.*
    - *Acronym: HB 2023*
    - *Dates: 9-13 October 2023*
    - *Poster presentation: "A Python Package to Compute Beam-Induced Heating in Particle Accelerators and Applications"*

- *Conference/Workshop name: Proton Precision Spectrometer Upgrade Workshop 2023, Geneva, Switzerland.*
    - *Acronym: PPS@HL-LHC*
    - *Dates: 22 February 2023*
    - *Presentation: "Beam-Coupling Impedance Update of CTPPS"*

6. Activity abroad:

7. Tutorship