Leonardo Sito

Metamaterials for beam-coupling Impedance mitigation at CERN

Tutor: Prof. Giovanni Breglio

co-Tutor: Prof. Francesco Fienga (DIETI)
Dr. Carlo Zannini (CERN)
Dr. Benoit Salvant (CERN)

Cycle: XXXVIII

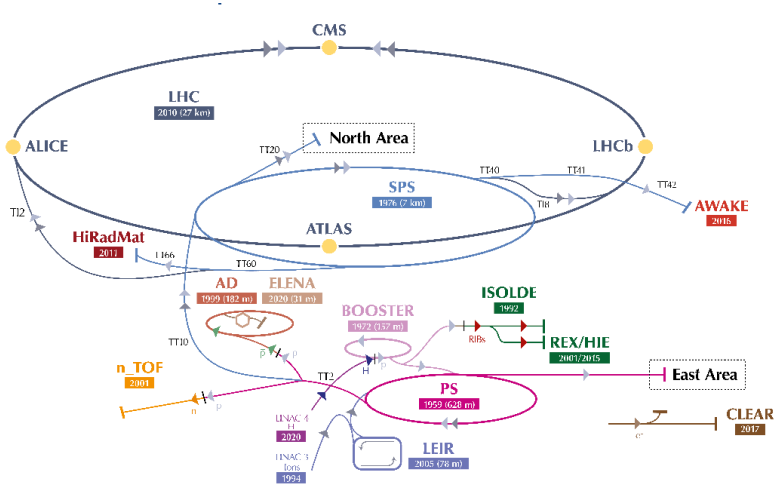
Year: First

My background

- **MSc degree:** Electronics Engineering @ UNINA
- **Research group/laboratory:**
  - **DIETI, OptoPowerLab**
  - CERN Beam, Accelerator and Beam Physics, Coherent Effects and Impedance (**BE-ABP-CEI**) section
  - CERN Experimental Physics, CMS TOTEM (**EP-CMT**)
- **PhD start date:** 01/01/2023
- **Scholarship type:** CERN Doctoral Student Program
- **Partner company:** European Organization for Nuclear Research (CERN)

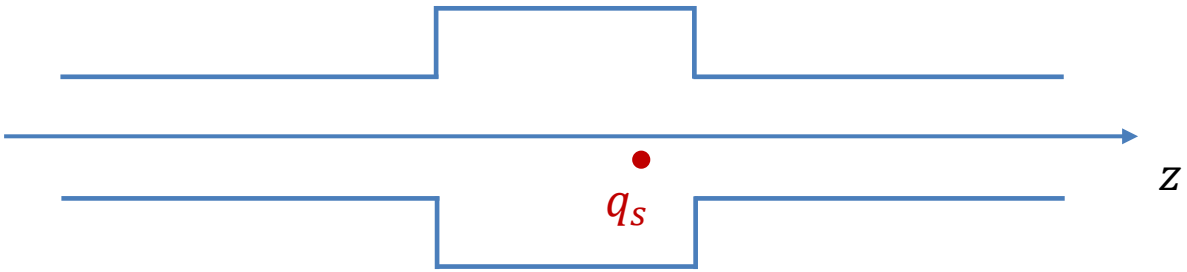
Research field of interest

European Organization for Nuclear Research (CERN) hosts the largest particle accelerator complex in the world.



- Accelerator machines: → "**metallic pipes**" (and cavities).
- **Bunches of particles** accelerated in several subsequent stages.
- In the last machines, the energy and the intensity is so high that **EM interactions play an important role**.

Section of a schematic vacuum chamber



Research field of interest

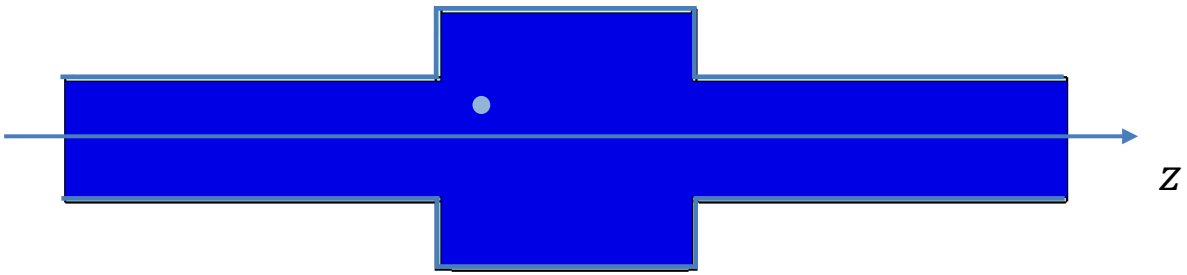
European Organization for Nuclear Research (CERN) hosts the largest particle accelerator complex in the world.

Due to field interactions:

- Instabilities in the particle motion
- Dissipated power on the device

This interaction is studied in the frequency domain with a formalism called Beam-Coupling Impedance

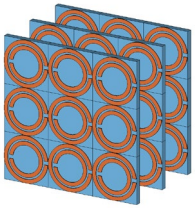
Section of a schematic vacuum chamber



Research activity: Overview

Main research topic:

Explore the possibility of using EM metamaterials to mitigate the beam coupling impedance



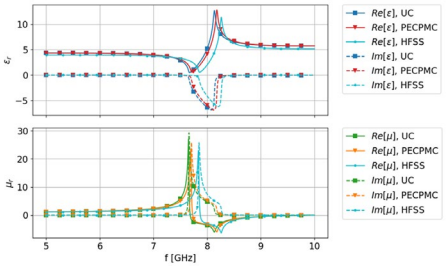
"Artificially structured materials that allow to engineer the interaction of fields with matter with properties that depend on constituent materials and geometry"

- Fundamental to reduce the Beam-Coupling Impedance since it could lead to severe issues.

Heat loads can bring to devices' breakage.

- *Two possible roads:*
  - ***Reduction of the effective surface impedance [1].***
  - *Metamaterial EM mode absorbers [2].*

- *Up to now:*
  - *Study on Beam-Coupling Impedance and Metamaterials.*
  - *Beam-Coupling Impedance simulation approaches (**CST**).*
  - *Metamaterial design and simulation approaches (**CST** and **HFSS**) + measurements.*



[1] A. Danisi, C. Zannini "Electromagnetic metamaterials to approach superconductive-like electrical conductivity"
[2] M.R. Masullo et al., "Metamaterial-Based Absorber for the reduction of Accelerator Beam-Coupling Impedance"

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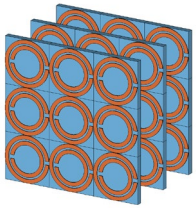

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In the next future:

- Design and characterize in measurement a metamaterial (respecting the properties in [1])
- Reproduce the experiment of [1] and go further in the testing.

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Summary of study activities

- **Ad hoc PhD courses:**
  - "**Statistical data analysis for science and engineering research**"
    - Lecturer: Prof. Roberto Pietrantuono, DIETI
  - "**Academic Entrepreneurship**"
    - Lecturer: Prof. Pierluigi Rippa, Silvia Cosimato, Nadia di Paola, DIE
  - "**Artificial Intelligence and Natural Language Processing**"
    - Lecturer: Prof. Francesco Cutugno, dr. Dr. Maria Di Maro, prof. Antonio Orilia, prof. Vincenzo Norman Vitale

- **PhD schools:**
  - "**Wakefields and Collective Beam Instabilities**", USPAS, Houston, Texas, USA.
    - Lecturers: Gennady Stupakov (SLAC), Ryan Lindberg (Argonne National Lab) Boris Podobedov (Brookhaven National Lab).
  - "**Surface Electromagnetics for Wireless Communications and Sensing**", Uni Trento.
    - Lecturers: Prof. Giacomo Oliveri, Dr. Salas-Sanchez Aaron A., Prof Marco Salucci
  - "**Spring School on Transferable Skills**"
    - Lecturers: Prof. Pasquale Maffia and Prof. Valeria Costantino, University of Naples Federico II

- **Conferences / events attended:**
  - Joint Accelerator Performance Workshop 2023 (**JAP23**), Montreaux, Switzerland.
  - Proton Precision Spectrometer 2nd Upgrade Workshop 2023 (**PPS2**), Geneva, Switzerland.
  - High Brightness Hadron Beams Workshop 2023 (**HB2023**), Geneva, Switzerland.
  - Proton Precision Spectrometer Upgrade Workshop 2023 (**PPS@LHC**), Geneva, Switzerland.

Summary of study activities

- **Seminars:**
  - 5G Academy - “Open Digital Framework”
  - “Multi-Robot Control of Heterogeneous Herds“
  - 5G Academy - “Il cloud e gli Hyperscalers / High Performance Computing”
  - 5G Academy - “Sustainable Strategy”
  - “The Laser-hybrid Accelerator for Radiobiological Applications”
  - “High Power Targetry R&D Program with the RaDIATE”
  - “Collaboration and target perspectives in framework of Snowmass”
  - “Beam-Beam Bremsstrahlung Beam-Size Effects and FCC-ee Beam Lifetime”
  - “Learning gene association networks using single-cell RNA-seq data: a graphical model approach”
  - “Accurate and Efficient Numerical Modeling Methods for Superconducting Circuit Quantum Information Processing Devices”
  - “Enhancing qubit readout with Bayesian Learning”
  - Nanoneuro – “The power of nanoscience to explore the frontiers of neuroscience”
  - “Nonlinear surface impedance of superconductors in high magnetic fields“
  - “Symbiotic Control of Wearable Soft Suits for human motion assistance and augmentation“
  - “Optimization of the High-Brightness Beam Performance of the CERN PSB with H-Injection”
  - “The design of the ENUBET beamline”
  - “Collective Effects in Lepton Circular Colliders and Synchrotron Light Sources”
  - “Predominantly electric “E&m” storage ring with nuclear spin control capability”
  - “Diffusive models and chaos indicators for non-linear betatron Motion”
  - “Ensuring Electronic Reliability Against CERN's Radiation Environment”

Products

[P1]	**Journal Paper:** V.R. Marrazzo et al., "**Experimental tests of a full analog fiber optic monitoring system suitable for safety application at CERN**", IEEE Transactions on Instrumentation & Measurement, DOI: 10.1109/TIM.2023.3250283.
[P2]	**Journal Paper:** F. Fienga et al., "**Direct measurement of beam induced heating on accelerator pipes with fiber optic sensors: numerical analysis validation,**" in IEEE Transactions on Instrumentation and Measurement, doi: 10.1109/TIM.2023.3279420.
[P3]	**Conference Proceeding:** L. Sito et al., "**Beam-Beam Long Range Compensator Mechanical Demonstrator**", IPAC 2023, Venice, Italy.
[P4]	**Conference Proceeding:** L. Sito et al., "**Validation of FBG sensors for thermal monitoring of the Central Beam Pipe of CMS**", SIE2023, Noto, Italy
[P5]	**Conference Proceeding:** L. Sito et al., "**A Python Package to Compute Beam-Induced Heating in Particle Accelerators and applications**", HB 2023, Geneva, Switzerland.
[P6]	**Conference Proceeding:** F. Fienga et al.,"**Improved Thermal Monitoring in Particle Accelerators Using FBGs: First Insights from the iPipe Project in LHC Run 3**", OFS-28, Hamamatsu, Japan, 2023.