ELECSIR: ELEctromagnetic Characterization and accelerator Structure Impedance Reduction

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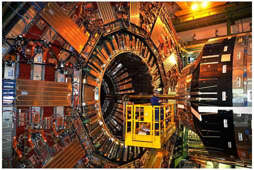
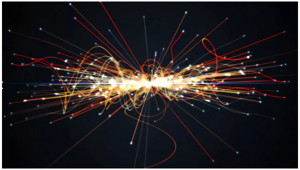
Introduction

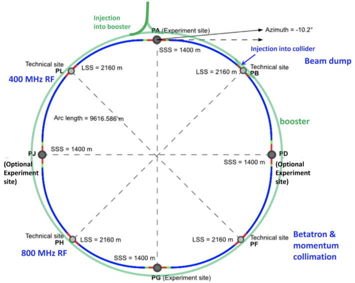
- Particle accelerators play a crucial role in various scientific and technological fields.

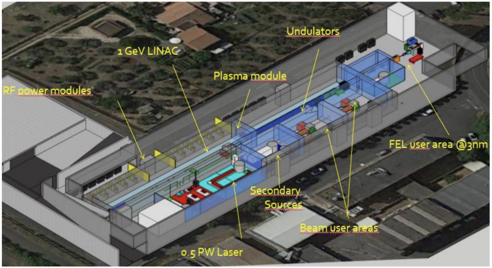




- Novel accelerator facilities, for both particle physics and technological applications, should provide beams with higher intensities and higher brightness. In order to preserve the stability and quality of such beams it is essential to understand and to handle the high intensity beam dynamics affected by the beam self-induced electromagnetic fields (wakefields).
- The proposed research aims to address these challenges and develop innovative solutions.

Introduction

The accumulated expertise at LNF, derived from designing and operating different accelerator facilities including the DAΦNE accelerator complex, enables us to propose research focused on impedance reduction and wakefield studies for diverse vacuum chamber components for two novel accelerator projects: **FCC-ee** and **EuPRAXIA@SPARC_LAB**.



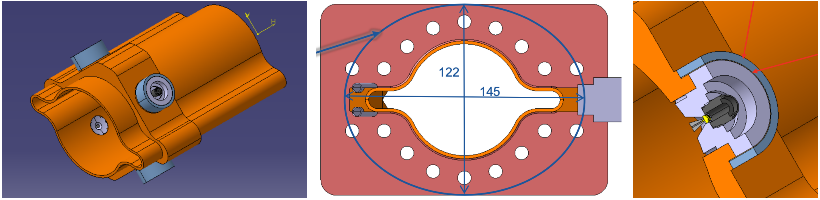


Research Objectives

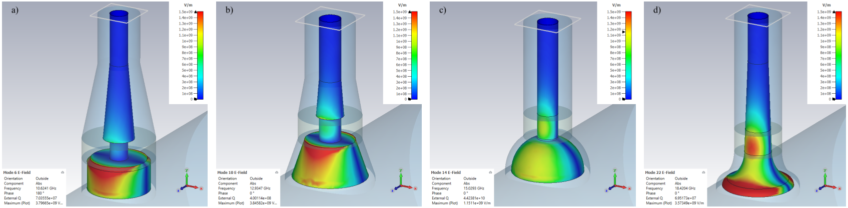
1. Develop Low-Impedance Capacitive BPM:
   - Conduct a literature review and formulate design specifications compatible with FCC-ee.
   - Develop the electromagnetic and mechanical schematic design for manufacturing.
   - Manufacture and perform accurate impedance and RF measurements on the test bench for the BPM prototype.
2. Study Resistive Wall Beampipe Impedance:
   - Analyze undulator section beam pipe and identify resistive wall effects for EuPRAXIA@SPARC_LAB.
   - Quantify the impact of resistive wall effects on beam stability to further refine the beam dynamics.
   - Develop strategies to suppress resistive wall-induced instabilities.
3. Study Beam Coupling Impedance for Dielectric Capillary:
   - Characterize the beam coupling impedance in longitudinal and transverse planes.
   - Analyze the impact of beam coupling impedance on beam stability.
   - Identify challenges and possible mitigation strategies.

State of the Art

- Recent Studies of Capacitive BPM Beampipe Section:



  - Preliminary studies for beam pipe shape and BPM electrodes
- Electromagnetic Simulations of Capacitive BPM Electrodes:

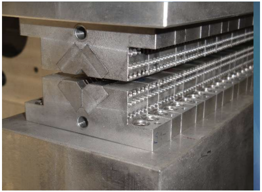


  - Due to the unprecedented dimensions, machines like FCC-ee, have a necessity to optimize and develop novel solutions also for BPM pickups, to optimise them from the impedance and heat transfer point of view.

State of the Art (contd.)

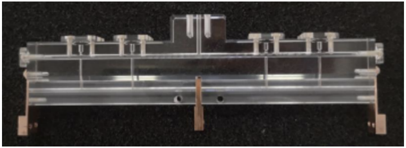
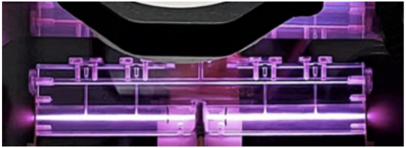
- Undulator region Resistive Wall Beampipe Impedance:





  - Investigate narrow beampipe resistive wall-induced instabilities and their impact on beam stability.

- Beam Coupling Impedance for Dielectric Capillary:

  - The estimation of the wakefield amplitudes with the extremely short bunches (order of 100 fs duration). The wakefield analysis will be extended in a very large frequency range, well above the THz threshold.

Methodology

BPM Simulations and Modeling → Design Development → Manufacturing → Test Bench Construction and Measurements

Simulations and Modeling → Undulator Beampipe Analysis → Quantifying Resistive Wall Effects → Propose Mitigation Strategies

Simulations and Modeling of Capillary → Characterize Beam Coupling Impedance → Analyze Impact on Stability → Identify Challenges and Possible Solutions

Work Packages and Activities

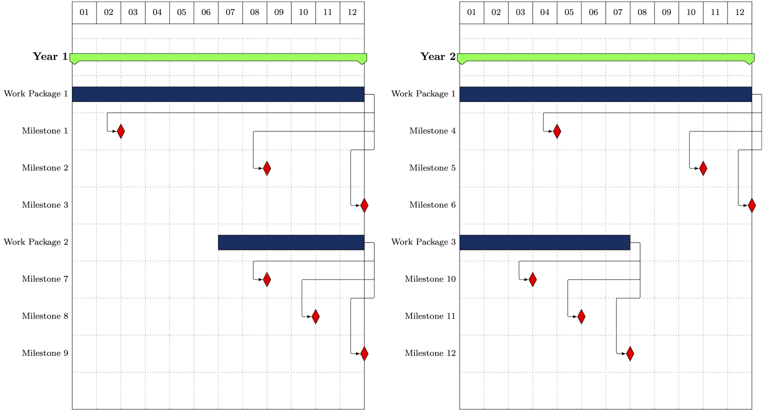
Work Package	Activities
1	Activity 1: Conducting a literature review on existing capacitive BPM designs and their performance in particle accelerators.
	Activity 2: Perform electromagnetic simulations and modeling to optimize the design parameters of the BPM.
	Activity 3: Develop the electromagnetic design of the BPM based on the established specifications.
	Activity 4: Develop the BPM prototype mechanical schematic drawing, according to suitable materials and manufacturing techniques.
	Activity 5: Construct a comprehensive test bench for measurements and experiments to evaluate the performance and accuracy of the BPM prototype.
	Activity 6: Conduct comprehensive test bench measurements and experiments to evaluate the performance and accuracy of the BPM prototype.
	Activity 7: Analysis of results and concluding remarks.
2	Activity 8: Analyze the undulator section beam pipe of the EuPRAXIA@SPARC LAB project to understand the resistive wall effects, and calculate resistive wall impedance.
	Activity 9: Quantify the influence of resistive wall effects on beam stability through analytical calculations and numerical simulations.
	Activity 10: Propose strategies to suppress resistive wall-induced instabilities and validate their effectiveness through simulations.
3	Activity 11: Characterize the beam coupling impedance in the longitudinal and transverse planes considering the specific geometrical features of the dielectric capillaries. The simulations also will be done in the presence of plasma.
	Activity 12: Analyze the impact of beam coupling impedance on beam stability through analytical calculations and numerical simulations.
	Activity 13: Identify potential challenges and limitations caused by beam coupling impedance and propose mitigation strategies.

Work Distribution and Milestones

Name	Activities Team Member will Take Part	Respective Percentage from FTE
Shalva Bilanishvili	Principal Investigator	100%
Mikhail Zobov	Activities 3, 7, 12, 13	10%
Enrica Chiadroni	Activities 7, 8, 12, 13	10%
Mauro Migliorati	Activities 7, 8, 9, 10	10%
Andrea Mostacci	Activities 2, 5, 6, 7	10%

Work Package	**Milestone**
1	Milestone 1: Completion of the literature review and formulation of the design specifications for the low-impedance capacitive BPM.
	Milestone 2: Finalization of the electromagnetic design of the low-impedance capacitive BPM.
	Milestone 3: Finalization of the mechanical schematic drawing for further manufacturing.
	Milestone 4: Manufacturing of the low-impedance capacitive BPM prototype.
	Milestone 5: Completion of the test bench measurements, including impedance measurements and validation experiments.
	Milestone 6: Report obtained results for Work Package 1.
2	Milestone 7: Characterization of the undulator section beam pipe and identification of potential resistive wall-induced instabilities.
	Milestone 8: Quantification of the impact of resistive wall effects on beam stability.
	Milestone 9: Concluding results for Work Package 2.
3	Milestone 10: Characterization of the beam coupling impedance in the dielectric capillary geometry.
	Milestone 11: Quantification of the impact of resistive wall effects on beam stability.
	Milestone 12: Concluding results for Work Package 3.

Timeline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Year 1
Work Package 1
Milestone 1
Milestone 2
Milestone 3
Work Package 2
Milestone 7
Milestone 8
Milestone 9
Year 2
Work Package 1
Milestone 4
Milestone 5
Milestone 6
Work Package 3
Milestone 10
Milestone 11
Milestone 12

Expected Outcomes

- Development of Low-Impedance Capacitive BPM:
  - Successfully conduct accurate impedance and RF measurements by the test bench experiments to validate the performance of the manufactured BPM prototype.
- Study of Resistive Wall Beampipe Impedance:
  - Characterization of the undulator section beam pipe and identification of resistive wall-induced instabilities for EuPRAXIA@SPARC_LAB, will help quantification and reducing of the impact of resistive wall effects on beam stability.
- Study of Beam Coupling Impedance for Dielectric Capillary:
  - Investigation of the beam coupling impedance and induced wakefields in the dielectric capillary geometry for EuPRAXIA@SPARC_LAB and developing mitigation strategies to suppress instabilities.

Significance and Impact

- Development of a low-impedance capacitive BPM will provide accurate beam position measurement while maintaining the stability for high-intensity bunch beams. Since there are similar requirements in performance for such devices also in 4th generation light sources, the impact of this research might contribute beyond the FCC-ee community.
- Understanding resistive wall effects and proposing mitigation strategies will improve beam stability in accelerator systems. If a reliable impedance model is made available, the accelerators, such as EuPRAXIA @SPARC_LAB, can be designed and configured with parameters that minimize their disrupting effect.
- The studies dedicated to the role of the plasma itself, in shielding or modifying the wakefields in dielectric capillaries and the estimation of the wakefield amplitudes assume a fundamental role in the implementation of the plasma wakefield acceleration.

Conclusion

The research project, ELECSIR, focuses on impedance reduction and wakefield studies for vacuum chamber components in the FCC-ee and EuPRAXIA@ SPARC_LAB accelerator projects.
The proposed solutions aim to optimize the design and performance of the capacitive BPM, develop mitigation strategies for resistive wall effects in the undulator section beam pipe, and address beam coupling impedance and induced wakefield effects in the dielectric capillaries.

Thank you!

Budget

Expense Category	Year 1	Year 2
PC Cost	27,168,33 euros	-
Software License	46,593 euros	-
Manufacturing Cost	-	15,000 euros
Test Bench Setup Cost	-	10,000 euros
Oscilloscope Cost	-	48,972 euros
Total	**73,761.33 euros**	**73,972 euros**