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

PhD Student: Vittorio Ferrentino

Cycle: XXXVII

Training and Research Activities Report

Academic year: 2023-24 - PhD Year: Second

Tutor: Prof. Pasquale Arpaia

Co-Tutor: Dr. Ewen Hamish Maclean (CERN)

Date: December 7, 2023

1. Information:

- **PhD student:** Vittorio Ferrentino **PhD Cycle:** XXXVII
- **DR number:** DR995870
- **Date of birth:** 17/02/1995
- **Master Science degree:** Electrical Engineering **University:** University of Naples Federico II
- **Scholarship type:** CERN Doctoral Student Programme
- **Tutor:** Prof. Pasquale Arpaia
- **Co-tutor:** Dr. Ewen Hamish Maclean (CERN)

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Dates	Organizer	Certificate[2]
5G Academy – Open Digital Framework	Seminar	3	0.6	17.01.2023	DIETI	Y
Multi-Robot Control of Heterogeneous Herds	Seminar	1	0.2	16.02.2023	Scuola Superiore Meridionale	Y
Study of the PS closed-pole half-unit model in Opera 3D. Analysis of the cropped model meshing structure. Study from literature on linear beam optics correction methods, non-linear beam dynamics and Hamiltonian approach at the 'Joint Universities Accelerator School (JUAS) – Course 1: The Science of Particle Accelerators'. Analysis of the PS-MU optics model results in MAD-X, using field harmonics from the magnetic model.	Research		9.2	01.01.2023 - 28.02.2023		

Analysis and Control of Functional Brain Networks	Seminar	1	0.2	09.03.2023	Scuola Superiore Meridionale	Y
High Power Targetry R&D Program with the RaDIATE Collaboration and target perspectives in framework of Snowmass	Seminar	1	0.2	30.03.2023	CERN	Y
Learning gene association networks using single-cell RNA-seq data: a graphical model approach	Seminar	1	0.2	31.03.2023	DIETI	Y
Accurate and Efficient Numerical Modelling Methods for Superconducting Circuit Quantum Information Processing Devices	Seminar	1	0.2	03.04.2023	DIETI	Y
How to publish under the CARE-CRUI Open Access Agreement with IEEE	Seminar	1.5	0.3	05.04.2023	DIETI	N
Bremsstrahlung Beam-Size Effects and FCC-ee Beam Lifetime	Seminar	2	0.4	11.04.2023	CERN	Y
Participation to the 'Joint Universities Accelerator School (JUAS), Course 2: the technology and applications of particle accelerators'. Exams successfully completed. Analysis of feed-down at injection in the PS caused by eddy currents. Study of the PS Main Unit Opera 3D magnetic model.	Research		9.5	01.03.2023 - 30.04.2023		

Lighter and shorter models created to analyze in detail the harmonics in the main parts of the magnet. Analysis of mesh. Optics measurements in the CERN Control Center (CCC) for the 2023 LHC Proton Commissioning at injection energy (450 GeV) and flat-top (6.8 TeV). Optics measurements for the 2023 LHC Ions Commissioning. Corrections calculated offline in Interaction Point 2. Optics measurements on the PS. Machine Development (MD) dedicated to test the optics at injection energy (~2 GeV) in bare-machine.						
2023 Spring School on Transferable Skills	Doctoral School	9.5	2	24.05.2023 25.05.2023	Department of Pharmacy, University of Naples Federico II, Naples, Italy	Y
Nanoneuro: the power of nanoscience to explore the frontiers of neuroscience	Seminar	1	0.2	03.05.2023	DIETI	Y
Optimization of a mobile clinic routing and scheduling problem in equitable vaccination outreach	Seminar	1	0.2	21.06.2023	DIETI	Y
Traffic Engineering with Segmented Routing: optimally addressing popular	Seminar	1	0.2	23.06.2023	DIETI	Y

uses cases						
Slawosz Uznanski - A CERN staff member, now ESA astronaut	Seminar	1	0.2	30.06.2023	CERN	Y
Study of the Opera 2D model of the PS-Main Unit (MU). Comparison with the 3D model. Study of a new PS-MU Opera 3D model with a new approach for improving the quality of the mesh structure. Reduced time to run simulations and lighter models. Optics measurements in the CCC for the 2023 LHC Proton Commissioning in high-beta scenario and non-linear optics measurements. Optics measurements on the PS, MD dedicated to test the optics at different energies (7, 18 and 23 GeV).	Research		7.2	01.05.2023 - 30.06.2023		
Academic Entrepreneurship	Course	17	4	29.05.2023 - 22.06.2023	DIETI	Y
Standard Model of Fundamental Interactions	Course	12	3	22.05.2023 - 30.05.2023	Scuola Superiore Meridionale	Y
Introduction to Deep Learning	Course	24	6	03.05.2023 - 06.06.2023	Scuola Superiore Meridionale	Y
“Rainbow´ Storage Ring Nuclear Transmutation with Spin Control Capability	Seminar	1	0.2	06.07.2023	CERN	Y
Optimization of the High-Brightness	Seminar	1	0.2	07.07.2023	CERN	Y

Beam Performance of CERN PSB with H-injection						
Beam Physics Research in IOTA-FAST at Fermilab	Seminar	1	0.2	17.08.2023	CERN	Y
Study of measured optics in the PS-MU at different energies in bare-machine. Study of PS Main Unit Opera 3D magnetic model. Simulation of the different power cycles to evaluate the harmonics saturation with energy. Study of the PS-MU transfer function. Optics measurements in the CCC for the 2023 LHC Ions Commissioning. Implementation of the IP2 Local Corrections computed offline. Optics measurements in the CCC on the PS. MD dedicated to test the optics at 14 GeV in bare-machine. First attempt to measure the optics with additional circuits turned on	Research		1.4	01.07.2023 - 31.08.2023		
Research in Energy Storage Systems for Automotive, Aerospace and Grid-connected Systems at the Ohio State University Center for Automotive Research	Seminar	2	0.4	15.09.2023	DIETI	Y
The design of the ENUBET beamline	Seminar	1	0.2	15.09.2023	CERN	Y

Reinforcement learning in CERN's accelerator & beyond	Seminar	1	0.2	29.09.2023	CERN	Y
Neutrinos in the lab and in the cosmos (2/3)	Seminar	1.5	0.3	18.10.2023	CERN	Y
Mixed Reality human-robot interface for remote operations in accelerator facilities	Seminar	1	0.2	27.10.2023	CERN	Y
Study of tune and chromaticity dependence on energy in the PS-MU in bare-machine. Comparison of optics measurements on the 23 GeV ramp and the measurements on single cycle plateaus. Analysis of the measurements with IP2 Local Correction for the 2023 LHC Ions Commissioning. Benchmark of the PS-MU magnetic model with magnetic measurements. Analysis of the possibility of modelling the PS-MU in ROXIE with a 2D model. Optics measurements in the CCC on the LHC for the 2023 Ion Commissioning. Measurements with IP2 Local and Global Corrections at different crossing angles. Optics measurements in the CCC on the PS. MD devoted to test the optics	Research		8.7	01.09.2023 - 31.10.2023		

dependence on the energy in bare-machine. Tunes and chromaticity scan at 10 GeV and 18 GeV trimming in the F8L circuit at different currents.						
Big Data Architecture and Analytics	Course	20	5	26.06.2023 - 20.07.2023	DIETI	Y
Picariello Lectures on Data Science – Robotics meets AI and 5G: Future is now	Seminar	2	0.4	06.11.2023	DIETI	Y
Diffusive models and chaos indicators for non-linear betatron motion	Seminar	1	0.2	17.11.2023	CERN	Y
Ensuring Electronic Reliability Against CERN's Radiation Environment	Seminar	1	0.2	01.12.2023	DIETI	N
Picariello Lectures on Data Science - Artificial Intelligence for Ocean Dynamics	Seminar	1	0.2	04.12.2023	DIETI	N
ICALEPCS 2023 Summary & ATS Flash Presentation Seminar	Seminar	4	0.8	07.12.2023	CERN	Y
Analysis of the measurements acquired on tune and chromaticity dependence on energy in the PS-MU in bare-machine with corrected Mean Radial Position (MRP). Comparison of optics measurements on the 23 GeV ramp with MRP corrections and measurements on single cycle plateaus	Research		6.2	01.11.2023 - 31.12.2023		

with MRP correction. Analysis of quadrupolar and sextupolar field component saturation from the PS-MU magnetic model. Benchmark of the PS-MU magnetic model with the B-train magnetic measurements. Study of a first PS-MU 2D magnetic model in ROXIE. Optics measurements in the CCC on the PS. MD devoted to measure the optics with the PS-MU additional circuits on (PFW and F8L) at injection energy (2.8 GeV), medium energy (10 GeV) and high energy (18 GeV).						

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	0.8	9.2	0	10
Bimonth 2	0	1.5	9.5	0	11
Bimonth 3	2	0.8	7.2	0	10
Bimonth 4	13	0.6	1.4	0	15
Bimonth 5	0	1.3	8.7	0	10
Bimonth 6	5	1.8	6.2	0	13
Total	20	6.8	42.2	0	69
Expected	30 - 70	10 - 30	80 - 140	0 – 4.8	

3. Research activity:

During the first months of the year, I attended the ‘Joint Universities Accelerator School (JUAS) – Course 1: The Science of Particle Accelerators’, and ‘Course 2: The Technology and Applications of Particle Accelerators’, 5 weeks long each, in Archamps, France. Each course foresaw a final examination consisting of 5 written exams plus one oral examination, which were successfully completed. Attending this school has been very important for the reserch activities related to the PhD as it has allowed to study some complex aspects behind the science of accelerator physics, providing an overall knowledge of the particle accelerator engineering and technology, and the phenomena occurring within them.

When JUAS was over, I restarted working on the PhD project. It focuses on the CERN Proton Synchrotron (PS) accelerator, which is one of the injectors of the Large Hadron Collider (LHC). The goal of the PhD project consists in the optics and magnetic modelling of the PS Main Units (MUs), and the validation of these models through beam-based measurements. The idea is to have a realiable magnetic model, simulating the field map in the magnet aperture and computing the field harmonics, and provide the simulated harmonics as input data in the optics model in order to simulate and predict the beam dynamics, and, in particular, its optics. The predicted optics will be then validated with beam-based measurements.

As general introductory description, in the PS tunnel there are 100 MUs, consisting of C-shaped normal-conducting combined-function magnets, meaning that each magnet generates a dipolar magnetic field plus high order field components. The multipolar field is generated with an hyperbolic shape of the iron pole profile. The individual MU is divided into 10 iron blocks, 5 focusing and 5 defosuing, meaning that they provide a quadrupolar field (or gradient) of opposite sign. Each MU is powered with 3 different coils:

- Main Coil (MC), generating the main magnetic field in the magnet aperture;
- two additional circuits, namely the Figure-of-eight loop (F8L) and the Pole Face Windings (PFW), generating higher order components needed to keep the beam circulating.

The PS-MU magnetic modelling and the related finite-element (FE) analysis are crucial for the project as they provide the input data (field harmonics) for the optics simulations. The FE software chosen for this purpose is Opera (2D and 3D), for its large flexibility in normal conducting magnets modelling and his accuracy for the numerical computation.

Many attempts have been done in the years concerning the PS-MU magnetic modelling. Thus, the first step to get in the project consisted in using the existing PS-MU magnetic models and try to understand how they could be improved and, eventually, to add new features. The first simulations launched with the existing PS-MU Opera 3D model have shown immediately some problems. The existing model turned out to be complex and very heavy; for this reason, the time required to complete a simulation was very long (order of days), and the model was not manageable at all in the pre-processing setup and post-processing computations. The reason behind these issues turned out to be the complexity of the meshing strcture, based on complex extrusion lines around the model geometry, which created a huge number of mesh elements in the model volume and, among some of these elements, the angle was so tiny that the simulations were corrupted by numerical errors.

Therefore, the existing PS-MU magnetic model needed to be redesigned in order to improve the meshing structure, keeping from the old model only the geometry, which of course cannot change. The principle of the extrusion lines was abandoned and a new meshing strcture, based on tetrahedral elements, was designed. In order to achieve reliable results in terms of field quality and accuracy in the area where the beam circulates (ideally, in the magnet center), the magnet aperture was discretized in different areas in order to set a different mesh size in the locations sourrounding the beam trajectory. This helped to get a finer mesh in a cylinder around the beam trajectory, in which the harmonics would be computed, and a coarser mesh far from the center. The new simplified meshing structure allowed to

lower the total number of mesh elements in the model volume and create regular angles between the elements. The new meshing structure has resulted in a lighter model which is now more manageable during the pre-processing setup and post-processing analysis, and requires a reduced time to complete a simulations (order of hours) with respect to the old model. Moreover, the new regular tetrahedral mesh should, in principle, avoid significant numerical errors.
To simplify further the PS-MU Opera 3D model, the idea of subdividing the entire magnet model into 5 smaller and lighter cropped models came up. These submodels consist in the following:

- 2 models reproducing the focusing and defocusing half-units with 3 iron blocks each;
- 2 models reproducing the fringe fields at the magnet extremities with two iron blocks each plus the far field area simulating the infinity;
- 1 model reproducing the focusing-defocusing transition area, with two iron blocks.

In order to do that, proper boundary conditions had to be set to have a representation as realistic as possibile of the full model and, clearly, of the real magnets. The new cropped models were very light and their simulations manged to be completed in less than one hour. Since the cropped models are approximeted models of the full (and more realistic) one, the error made by using them in place of the full model was evaluated. It turned out that the error was below 1% for the computation of the dipolar and quadrupolar field component, while it was below 3% for the sextupolar component. Hence, the creation of the cropped models has allowed to rely on lighter models with respect to the full-model, which are very simple, flexibile and run very quickly, approximating the full model with a maxium error of 1%, up to the quadrupolar component.
In addition to the 3D models, 2D models for both the focusing and defocusing half-unit cross-section have been designed in Opera 2D. This has helped to launch very fast simulations with results available in less than two minutes. It turned out that the 2D models represent a good description of the real magnets at low energy, while, at high energies, the iron saturation makes the error between the 2D and 3D models larger, in particular when fringe fields are analyzed.
The simulated field has been carefully compared with the magnetic measurements with the B-train system. The error between the simulated field in Opera 3D and magnetic measurements has been assessed to be below 1%.
The improvements achieved in the PS-MU magnetic modelling in terms of simulated field quality, harmonics computation and lightness of the model have allowed to obtain a reliable model which can predict the field harmonics in the magnet aperture in a reasonable time, switching from the days needed to the old model to the hours of the new 3D model (and minutes for the 2D one). With such model, the harmonics can be computed and provided as input to the optics model to simulate the beam dynanics.

The 2023 has been an year characterized by a significant number of beam-based measurements in the CERN Control Center (CCC), which are usually called Machine Developments (MDs). The 2023 optics measurements campaign has mostly been focused on the bare-machine configuration, meaning that only the Main Coil is turned on in each MU, while the additional circuits (F8L and PFW) are off. This configuration represents the simplest one for the PS-MU operation, so the easiest to model as a first step. Many power cycles in bare-machine have been prepared by the PS operators, from the injection energy of 2.8 GeV up to 23 GeV: 2.8 GeV, 5 GeV, 7 GeV, 10 GeV, 14 GeV, 18 GeV and 23 GeV. Each power cycle is characterized by a first plateau at injection energy, followed by a ramp-up, a final plateau at the specific energy of the cycle (e.g., 10 GeV, 18 GeV, etc.) and a final ramp-down for extraction. For each power cycle, the optics measurements have been carried out on the plateau, where the field/current/energy are constant.

The two main parameters for the optics measurements have been the horizontal and vertical tunes, defined as the number of beam oscillations per turn in the horizontal and vertical plane, Q_x and Q_y respectively, and the horizontal and vertical chromaticity, Q'_x and Q'_y respectively, defined as the ratio between the variation of tune (in that plane) ΔQ and the variation of the momentum Δp. The monitoring of both parameters is essential for the beam stability and the machine operation.
For the beam optics measurements, the tune and chromaticity evolution on the cycles pleateaus have been measured, and the average of the different shots provided the tunes and chromaticity at that specific energy. By carrying out these measurements on the plateau of each power cycle, it was possible to evaluate the tune and chromaticity dependence on energy in bare-machine configuration.
The highest energy at which it was possible to measure in bare-machine was 23 GeV. This was a very interesting power cycle, as the ramp preceding the 23 GeV plateau was crossing all the lower energies at which it was possible to measure thorugh the individual power cycles (basically, the ramp for 23 GeV passes by 5 GeV, 7 GeV, 10 GeV, etc.). Hence, continuous measurements of tunes and chromamticity have been acquired on the 23 GeV ramp and compared with measurements from individual cycle plateaus. This comparison has shown discrepancies as the measurements from the individual plateaus were off the continuous measurements path at some energies.
The PS-MU magnets are iron dominated, for this reason they are affected by iron hysteresis effects. The power cycle under investigation during the measurements is preceded by a different power cycle (devoted to other user/tests) at whatever energy. The ensemble of the active power cycles which are running in the machine is called Supercycle, which repeats cyclically. Hence, the power cycle preceding the cycle under investigation has an impact on the residual field B_r in the PS-MU iron during the optics measurments on the cycle under investigation. In this context, the residual magnetic field in the magnet is normally called Remanent Field. To avoid that different power cycles at different energies preceding the cycle under investigation (in the supercycle) might have a different contribution to the remanent field, and so to impact differently on the measurements, it was decided to repeat all the measurements on the single cycles plateaus within the same day, trying to keep the position of the cycle in the supercycle always the same. In this way, the cycle under investigation was preceded by the same power cycle and the remanent field did not change significantly for each repetition of the supercycle. Indeed, this turned out to be a good strategy as the agreement between the continuous measurements on the 23 GeV ramp and the measurements from the individual plateaus (acquired on the same day with a fixed position in the supercycle) improved significantly.
Before comparing the optics measurements with the optics simulations, the idea of assessing the beam position in the magnet aperture came up. Indeed, from the PS-MU magnetic model, the harmonics are computed through field integration along a cylindrical surface centered in the center of the magnet. Moreover, the optics simulations assume as closed reference orbit the one corresponding to the center of the magnet. For these reasons, it became crucial to look at the real position of the beam during the optics measurements as, in case it turned out to be off-center, the beam would have been affected by field harmonics not fully considered within the integration in the magnetic model. Thus, the beam Mean Radial Position (MRP) was measured and analyzed on each power cycle. It was noticed that, when the ramp starts and ends, the MRP had a significant negative or positive shift, due to the strong dB/dt when approaching or leaving the ramp, and its value on the plateau was far from 0, with peaks of 30 mm. So, as guessed, with such MRP, during the optics measurements the beam was significanlty off-center, while, in simulation, the harmonics were computed on a cylindircal surface around the very center of the magnet. Therefore, to correct the MRP became a need in order to properly compare the simulations with the measurements.

The MRP was corrected on the individual cycles plateaus and new tunes and chromaticity measurements, on each cycle plateau with MRP corrections trimmed in, were acquired on the same day. In addition to that, in the supercycle, a gaussian cycle was put just before the power cycle under investigation to rely on a fixed value of the remanent field in the MU iron. MRP corrections were also implemented on the 23 GeV ramp, as well as on its plateau.
In these conditions and with the MRP corrections, the measurements on the individual cycle plateaus and the continuous measurements on the 23 GeV matched within the error bar. This led to the conclusion that dynamic phenomena occuring within the 23 GeV ramp, such as beam instabilities arising from eddy-currents harmonics, were not affecting tunes and chromaticity measurements even without relying on the contribution of the additional circuits (bare-machine). Moreover, the analysis carried out has shown that the continuous measurements on the 23 GeV ramp are sufficient to describe the optics dependece on the energy, without the need of specific measurements on each cycle plateau. The continuous measurements on the 23 GeV ramp have shown a clear saturation of the tunes and chromaticity at high energy (from 18 GeV on), which might be explained with the models.

The measured optics represents the reference with which the PS-MU models can be validated. The optics model has been implemented with the Methodical Accelerator Design – X (MAD-X). Historically, the PS-MU optics model in MAD-X has been based on matched models, meaning that the magnet strengths (or harmonics) in the model have been chosen in order to match the simulated optics with beam-based measurements; hence, it has always been an empirical model. The goal of the PhD project is instead to predict the beam optics by using the harmonics simulated from a magnetic model.
For this purpose, after simulating the field map with the magnetic model in Opera 3D, the next step consisted in importing into MAD-X the field harmonics computed in Opera, converted into magnetic strengths (there is a direct correlation between field harmonics and magnet strenghts).
Tunes, in abscence of feed-down effect, are affected only by the quadrupolar magnetic field component (B_2), while the chromaticity is affected by the sextupolar component (B_3). The magnetic field was integrated in Opera for both the focusing and defocusing half-units, representing the integrated field in the core of the half-units, $B_{2,CORE,F}$ and $B_{2,CORE,DF}$, respectively, and at the extremities of the magnet to consider the harmonics from the Fringe Fields (FF) for the focusing and defocusing parts, $B_{2,FF,F}$ and $B_{2,FF,DF}$, respectively. With the same approach, the $B_{3,CORE,F}$, $B_{3,CORE,DF}$, $B_{3,FF,F}$ and $B_{3,FF,DF}$ integrated harmonics have been computed and imported in the optics model. This process has been carried out for each power cycle analyzed during the measurements, and this allowed to compute the harmonics at 2.8 GeV, 5 GeV, 7 GeV, and so on.
Once the harmonics were imported in MAD-X, the optics simulation could be launched for a specific energy. After the optics simulations were completed for the different energies, it has been possible to compare the simulated optics at a specific energy with the measurements. From these comparisons, it came out that the optics simulations reproduce correctly the measurements with a maximum error of the level of $5 \cdot 10^{-2}$ for the tunes. In addition, the simulations have shown a saturation of the predicted tunes and chromaticity at high energies, as well as it has been observed from the measurements. The saturation of the optics in the PS-MU has been explained with the help of the PS-MU magnetic model. Indeed, by plotting the different magnetic strengths related to the quadrupolar and sextupolar component with respect to the energy, it has been observed that they saturate at high energy. This phenomenon is more evident at the magnet extremities, due to the end effects (Fringe Fields).
Hence, the saturation of both the simulated and measured optics in bare-machine has been explaneid through a saturation of the harmonics, arising because of the iron saturation. Indeed, a further analysis

of the field map within the MU iron has shown that the pole edges are the first locations to saturate, losing their ability of providing a quadrupolar contribution to the total field in the magnet aperture. Therefore, the combination of the PS-MU magnetic and optics models manage to predict the tunes and chromaticity with good accuracy with respect to the optics measurements, and their saturation at high energy. However, the matching is not perfect yet, there are still improvements that can be done within the models.

During the year, free time has also been devoted to collaborate with the Optics Measurements and Corrections (OMC) team for the 2023 LHC Protons and Ions Commissioning. In particular, I have followed and documented the computation of new Local Corrections in Interaction Point (IP) 2 and the optics measurements carried out with them in the machine. These corrections allowed to improve the optics of the beams in the LHC, ensuring better performances for the collisions in the experiments.

4. Research products:

Journal Papers

Title: Analysis of Powering and Quench Protection of the SIGRUM Superconducting Combined Function Dipole Magnet;
Authors: Vittorio Ferrentino, Pasquale Arpaia, Antonio Gilardi, Mikko Karppinen, Charilaos Kokkinos, Emmanuele Ravaioli;
Journal: IEEE Transactions on Applied Superconductivity;
Status: Published in 2023.

Title: First operational dodecapole correction in the LHC;
Authors: J. Dilly, V. Ferrentino, M. Le Garrec, E. H. Maclean, L. Malina, T. Persson, T. Pugnat, L. van Riesen-Haupt, F. Soubelet, and R. Tomás;
Journal: Physical Review Accelerators and Beams (PRAB);
Status: Published in 2023.

Conference Papers

Title: Optics Correction Strategy for Run 3 of the LHC;
Authors: T. Persson, J.Cardona, F. Carlier, A. Costa Ojeda, J. Dilly, H. García Morales, V. Ferrentino, E. Fol, M. Hofer, E.J Høydalsvik, J. Keintzel, M. Le Garrec, E.H. Maclean, L. Malina, F. Soubelet, R. Tomás, L. Van Riesen-Haupt, and A. Wegscheider;
Conference: 13th International Particle Accelerator Conference (IPAC);
Status: Published in 2023.

Title: Challenges of K-modulation measurements in the LHC Run 3;
Authors: F. Carlier, A. Costa Ojeda, J. Dilly, V. Ferrentino, E. Fol, M. Hofer, J. Keintzel, M. Le Garrec, T. Levens, E. H. Maclean, T. H. B. Persson, F. Soubelet, R. Tomás Garcia, L. Van Riesen-Haupt, A. Wegscheider;
Conference: 14th International Particle Accelerator Conference (IPAC);
Status: Accepted in 2023.

Title: LHC Run 3 optics corrections;
Authors: F. Carlier, J. Cardona, A. Costa Ojeda, R. De Maria, J. Dilly, V. Ferrentino, E. Fol, M. Hofer, J. Keintzel, M. Le Garrec, E. H. Maclean, T. H. B. Persson, F. Soubelet, G. Trad, R. Tomás Garcia, L. Van Riesen-Haupt, A. Wegscheider;
Conference: 14th International Particle Accelerator Conference (IPAC);
Status: Accepted in 2023.

5. Conferences and seminars attended

No conferences attended.
Seminars attendend are reported in the above table.

6. Periods abroad and/or in international research institutions

No activities carried out abroad.

7. Tutorship

No tutorship activities carried out during the year.

8. Plan for year three

Concerning the courses/Phd schools, I plan to reinforce soft and technical skills by attending some courses among the ITEE ad hoc courses, which can be useful for the PhD program.

The title of the thesis should be 'Optics and Magnetic Modelling of the CERN Proton Synchrotron Main Units and beam-based measurements'. As it was largely described in the Research activities paragraph, the PhD project consists in an innoavative approach to predict the beam dynamics within the PS-MU, based on a magnetic model, which simulates the field harmonics, and an optics model using as input data the simulated harmonics and predicting the beam dynamics in the machine. The optics and magnetic models are then validated with beam-based measurements.
The matching between the measurements and predicted optics in bare-machine is already good, as described in the Research Activities of the year. However, some approximations currently in the model need to be improved. In particular, the real magnets in the PS tunnel are bended, while the PS-MU magnetic model in Opera 3D is straight. The radius of curvature of the real magnets is not relevant, but, if implemented in the magnetic model, it might have a slight impact on the harmonics computation, which could in principle reduce the discrepancies between measurements and simulations.
In addition, the bare-machine configuration analyzed so far represents the simplest scenario for the PS operation. Indeed, the PS-MUs are featured with two additional circuits for the high order components corrections, allowing to keep the beam circulating. As a consequence, these additional coils have to be included in the magnetic model, and the harmonics arising from them have to be considered for the beam dynamics simulation in the optics model.

A further step would be to have a second magnetic model by using a different software. The idea is to model the PS-MU in ROXIE, which is a finite-element software largely used in the magnet community for normal and superconducting magnets modelling, and compare the harmonics from ROXIE with the harmonics from the Opera 3D model.
Some changes will also be implemented in the MAD-X optics model, trying to insert new features to represent better the effect of the air gaps between the iron blocks and the Fringe Fields. This could also led in principle to new integration approaches in the magnetic model (for instance, integrating in each iron block and not thorugh the whole main-unit), depending on the results of the matching between simulations and measurements.
New beam-based measurements should be carried out from March on with the additional circuits turned on. These measurements have started this year during the last days available for optics measurements, but there is nothing relevat to report at the moment.

Concerning the conferences attendance, the plan is to attend the 15th International Particle Accelerator Conference (IPAC), in Nashville, Texas, USA. If this will be the case, some abstracts and papers will be submitted and presented, showing the results obatined so far on the PhD project, as well as some interesting results which came up from the measurements during the 2023 LHC Ions Commissioning.